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THE EFFECT OF WEATHER UPON THE CHANGE IN WEIGHT OF A COLONY OF BEES DURING THE HONEY FLOW

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INTRODUCTION

The annual honey crop of a colony of honeybees is dependent upon a considerable number of factors, part dealing with the activities of the bees and part resulting from the various external factors influencing the secretion of nectar by the honey plants of the locality. Demuth (*8, p. 18*)[1] has shown this interrelationship by pointing out that there are four factors which combine to make the honey crop: A surplus population in the colony over and above the bees necessary for colony maintenance, a predominance of the storing instinct and the control of swarming, honey plants growing under optimum conditions, and weather suitable for the secretion of nectar and the gathering of it by the bees. If any one of these factors is reduced to zero, the crop is zero, and if any one factor is reduced one-half, the crop is one-half the maximum. Naturally, so long as the factors do not rest on a mathematical expression, it is impossible to interpret them with exactness, but every experienced beekeeper realizes this interrelationship; it is therefore safe, as a working hypothesis, to accept these factors as real and fundamental.

Most of the work done on beekeeping subjects has dealt either with methods of obtaining for the colony a surplus population at the right time for the gathering of the crop, or with the management of the colonies so as to induce the bees to expend their energy in gathering, which, as every experienced beekeeper knows, means the control of swarming and any other instinctive activity which might tend to reduce the manifestation of the gathering instinct. The last two factors of those above mentioned have to a considerable degree been neglected, doubtless because they are outside the control of the beekeeper in any given location. Since the honey crop is so intimately connected with these factors, however, it is unwise to neglect them. There are extensive records and lists of the plants which furnish nectar in quantities sufficient to make beekeeping profitable in the various parts of the country, and there are certain results of botanical investigations which bear on this subject, but as a rule these results have not been part of the beekeeping literature. Almost no attention has been paid to the effect of weather factors on the gathering of the crop.

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[1] Reference is made by number (italic) to "Literature cited," p. 50.

The purpose of this bulletin is to present information on the relationship existing between changes in the weight of a colony of bees during a honey flow and the prevailing weather conditions, based on data obtained at the Bee Culture Laboratory, Somerset, Md., from February to November, 1922, and for the month of May, 1923. The major problem during this time was an intensive study of colony temperatures, but this experiment necessitated the recording of changes in the weight of at least one colony of bees hourly throughout the day and night for long consecutive periods. At the conclusion of the experiment a hasty survey of these changes immediately revealed an abundance of interesting data which seemed to throw considerable light upon the relationship of changes in hive weights to outside conditions. Although the data herein recorded on the factors influencing changes in weight are not as complete as they should be to carry such a problem to a final conclusion, the subject is here presented from the material available in the hope that it will serve as a stimulus to investigators in different great honey-producing areas to study the relationship of weather to honey production. A problem like this can not be solved without such comparative data. Information of this sort covering the principal honey-producing sections of the United States would be of inestimable value in the furtherance of beekeeping. A knowledge of existing honey flora and a correlation of weather conditions with bee behavior should help the prospective beekeeper in choosing the best beekeeping locality. At the present time there is no method of predicting whether a locality will prove profitable to the beekeeper except by the results obtained by other beekeepers. It would be well to know just why certain plants produce nectar in one locality and not in another, and, more important still, to discover if possible the laws underlying the relationship between bees, nectar-producing plants, and weather conditions as they influence the results of the beekeeper, and to determine, if possible, which are the most important factors upon which the honey crop depends.

In this discussion the results of the relationship of bees and nectar-producing plants are shown either as surplus honey or as increase in the weight of the colony. The two results are inseparable as far as the present work is concerned. No effort was made to study plant behavior and bee behavior as separate subjects, but the results of the two working together as one, and recorded as "colony weight changes," have been studied in their relation to the prevailing weather conditions.

It is a very common practice among the best beekeepers to maintain what is known as a scale colony. A colony of average strength is usually chosen for this purpose and is placed on scales in the apiary. This colony is weighed once or twice a day, usually in early morning and after the bees have stopped flying in the evening. Such weighings however, are usually made in a haphazard manner, without much care that the weighings are recorded at an exact time each day. Such records give little information except that they indicate in a rough manner the trend of the honey flow. Unfortunately, even such records as these are not available for most localities.

Records of careful hourly weighings of colonies are scarce. Dufour (*10*) pointed out the value of hourly weighings and showed how enormously the hourly changes in weights throughout the day may vary on days showing the same net gain. Figure 1, taken from data used in the present investigation, illustrates graphically the activities on two days when the net gains were approximately the same. The times of regaining the original weights are shown at the intersections of the curves with the zero line. Dufour (*10*) gives information on the weather conditions only in a general way, during the time when he carried on his experiments, and it is therefore impossible to calculate the exact relationship in his investigation between the changes of colony weight and the weather.

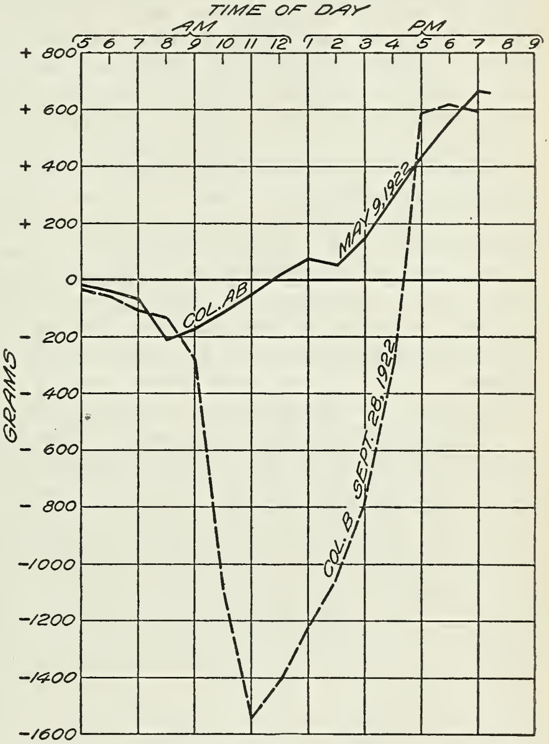

FIG. 1.—Graphs of hourly changes in the weight of a colony of bees on two days when the net gains were approximately the same. The solid line presents the changes on May 9, the other those on September 28, 1922

In any discussion of changes in colony weight it is important to keep in mind the fact that these changes are brought about by two factors working jointly, both influenced by weather conditions. These factors are the secretion of nectar by the plants and its collection by the bees. Of the two factors, investigators have given more attention to nectar secretion than they have to bee behavior. Even in the field of nectar secretion there is no general agreement as to the relative value of the influencing factors; certainly none based on a mathematical determination of their relative importance.

Kenyon (*21*) and Kenoyer (*20*) called attention to Dufour's work in the hope that others would carry on similar experiments, but no extensive research seems to have been undertaken until the present work. Discussions of factors influencing nectar secretion alone are often somewhat misleading to the beekeeper, because factors which may stimulate or retard nectar secretion may not be apparent at the hive as shown by changes in weight or in the honey crop.

Considerable work has been done on the problem of nectar secretion and the influence upon it of temperature, humidity, altitude, latitude, and similar factors, but little is on record other than casual observations by beekeepers as to the influence of these factors on bee behavior during the active season, either in or out of the hive. The works on nectar secretion by Bonnier, Behrens, deLayens, and Kenoyer stand out prominently in this line. These writers and others have made important contributions on the mechanism of nectar secretion and on the factors influencing it. Unfortunately, only a comparatively few plants have been studied for nectar secretion from a physiological point of view, and when thus studied the number of individuals of a species has of necessity been small. Too often observations have been confined to flowers cut from the plant in order to control the governing factors, such as temperature and humidity, thus leading to erroneous conclusions. Loftfield (*22, p. 101*) has pointed out in the study of stomatal movement the great difference in behavior between cut stems and potted or field plants of the same species.

It is quite evident that the factors influencing nectar secretion are not necessarily synonymous with those affecting the changes in weight of a colony of bees during the honey flow. In glancing over papers dealing with nectar secretion there is usually no clear distinction drawn between the amount of nectar secreted and the surplus honey gathered by bees, and one might assume that what affects one should affect the other in like manner. This appears not to be the case, as indicated by the data at hand. It is also evident that data on nectar secretion for certain species of plants should be limited largely to the species in question and not used for comparison with other species in other localities. If climatic conditions affect the behavior of bees in the same manner as they affect nectar secretion, one would expect to find a close correlation between factors reputed to be favorable both to nectar secretion and to increases in the weight of colonies of bees, but such a correlation does not seem to exist. It seems, therefore, either that the proper combination of factors influencing nectar secretion has not been discovered, or that the effect of weather conditions upon the behavior of bees is entirely different from their effect upon plants. It has previously been impossible to determine by judging from the changes in the weight of a colony of bees whether weather conditions influence the more greatly bee behavior or nectar secretion; and, from the standpoint of the practical beekeeper, the influence of weather upon colony weight is far more important than its influence upon either nectar secretion or bee behavior alone.

METHOD OF OBTAINING DATA

From February to November, 1922, continuous records were made of a colony of bees placed on platform scales sensitive to 10 grams. Owing to the nature of the principal problem under investigation, hive temperatures, the hive was left unprotected and certain of the weight records were rendered useless, water remaining on the hive and bottom-board after rains causing too great errors in the weight records. During most of the month of June, 1922, alterations were necessary in the apparatus for recording temperatures in this colony, and weight records are therefore not available for this month.

A standard 10-frame Langstroth hive was used to house this colony. Previous to the honey flow two brood chambers were in use, and a few days before the beginning of the honey flow the colony was manipulated to prevent swarming and additional supers were added. The colony was left in this condition until, in June, alterations were made in the temperature-recording apparatus.

During May, 1923, two colonies placed side by side, both on equally sensitive scales, were observed for additional data covering another honey flow. Both colonies were in standard 10-frame hives, each having two hive bodies for brood and three, above a queen excluder, as supers. In this case the colonies were given ample room for brood rearing and storage of nectar, and made no attempt to swarm. Precautions were taken to shield these hives from rain, by placing a sloping board over the entrance of each colony in such a manner that rain would not fall on the bottom-board, while there would be free access to the bees. A false roof was suspended over the outer cover of the hive, which caught the rain and shed it beyond the hive walls. A light wooden framework over the two colonies was covered with canvas. In case of a light rain when the bees were still flying the canvas cover was not used, but during periods of hard dashing rains the canvas was dropped so low as to surround the hives completely and prevent any water from collecting on them.

Weighings were made hourly throughout the 24 hours of each day, including Sundays and holidays, three persons being assigned to the work on 8-hour shifts. One of the unfortunate circumstances connected with working on such a problem at Somerset, Md., is that the main honey flow is exceedingly short (seldom over 10 days to 2 weeks), thus increasing the probable error in all calculations by reducing the number of possible observations. The correlation coefficients for the spring honey flow are based on the one colony in 1922, and on the two colonies in 1923. For conclusions relative to the fall honey flow only the figures for the one colony of 1922 are available.

In order to calculate the relationship between changes of weight and weather conditions during the honey flow, only those days showing a net gain of 980 grams or over were used for the spring honey flow. The calculations for the fall period include all days from September 4 to October 5, irrespective of gains or losses; the two sets of data are therefore not strictly comparable.

Hourly thermograph and hygrograph records were made for use in calculating the mean temperatures and relative humidity; the mean of maximum and minimum temperatures was not used. Hartzell (*16*) has pointed out the chances of error in endeavoring to correlate the average of maximum and minimum temperatures with various biological activities.

A rather rough record was kept of sunshine and cloudiness, but in all calculations the records of the United States Weather Bureau for Washington, D. C., were employed. There is a distance of 6 miles between the Weather Bureau Station in Washington and the Bee Culture Laboratory, at Somerset, Md., and it was found that only negligible differences existed beween the recorded hours of sunshine for the two places. Records of solar radiation were also available through the kindness of Prof. H. H. Kimball, of the Weather Bureau, these being taken at American University, in Washington, about 1 mile from the Bee Culture Laboratory.

Calculations relating to the effect of wind upon honey production were not made. The anemometer maintained at the Bee Culture Laboratory was so located for another purpose that its records were not applicable to this problem.

The principal source of nectar available to the bees in this experiment was that from tuliptree (*Liriodendron tulipifera*). It is an excellent honey plant in this locality, yielding abundantly for about two weeks in early May. Since it blooms so early in the season, it is of the utmost importance that the beekeeper have his colonies strong, otherwise its nectar is wasted with the exception of what little is used for brood rearing. Occasionally black locust (*Robinia pseudacacia*) furnishes considerable nectar, but this plant is not dependable in this region. The period of the secretion of black locust coincides closely with that of tuliptree. In 1922 the bees worked on locust actively for several days, while scarcely a locust blossom was seen in 1923. A rainy May, especially rain for the first few weeks of May, spells crop failure for the beekeeper of this region. In this connection, attention should be called to the statement of Kenoyer (*19*) that a rainy May scarcely fails to precede a good honey season in the State of Iowa. This emphasizes the statement made earlier in this bulletin that with the present limited knowledge of the various honey plants a general application should not be made of data secured in a single locality with a certain species of plant. Kenoyer's work was based on data obtained in the clover region.

The coefficients of correlation between the various factors were calculated from the following usual formula for biometric calculations (*7*):

$$r=\left(\frac{\Sigma xy}{n}-\overline{xy}\right)\frac{1}{\sigma_x\sigma_y}$$

Probable errors were calculated from the formula—

$$PE_r=\frac{.67449}{\sqrt{n}}(1-r^2)=\chi_1(1-r^2)$$

The values of χ_1 were taken from Pearson (*29*), and the values of $1–r^2$ from Miner's Tables (*25*)[2].

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[2] All mathematical calculations are based on accepted biometric methods. The writer here records his thanks to Dr. Sewall Wright, of the Bureau of Animal Industry, for his unfailing assistance and advice in this phase of the work.

It may not be amiss at this place to give, for those not well versed in biometrics, a brief explanation of the terms "correlation" and "probable error." The following quotation is taken from Bowley (*3, p. 316*):

> When two quantities are so related that the fluctuations in one are in sympathy with fluctuations in the other, so that an increase or decrease of one is found in connection with an increase or decrease (or inversely) of the other, and the greater the magnitude of the changes in the one, the greater the magnitude of changes in the other, the quantities are said to be *correlated.*

We may have either a positive or a negative correlation. When a change in one quantity or variable is accompanied by a direct change in the other the correlation is said to be positive. A perfect positive correlation has the value of 1. When the correlation is less than perfect it must be written as a decimal of one, such as .75. When the relationship between two quantities or variables is indirect, such as an increase in one being accompanied by a decrease in the other, the correlation is negative. A perfect negative correlation has the value of -1. Such a relationship less than perfect must also be written as a decimal and is always preceded by a minus sign. Coefficients of correlation state in numerical terms the relationship between two variables. Graphs are useful in showing relationship between two variables, but they do not give numerical correlation values, and it is often difficult from the study of a graph to discover slight relationship or entire absence of relationship; this difficulty does not exist in the case of correlation. It is often convenient to think of a coefficient of correlation in terms of percentage; thus, a correlation written 0.8654 may be read as 86.54 per cent.

The probable error is a term applied in biometrics to make corrections in a calculation where complete data are lacking. Sample measurements must be made preliminary to a biometric calculation and it is rarely possible to obtain a complete series of samples. For instance, in calculating the correlation between temperature and the change in colony weight we may have the changes in weight occurring at 80°, 81°, 82°, and 84° F., the change at 83° F., being for some reason impossible to secure. The probable error gives the measure of unreliability due to lack of sufficient data. Obviously, the smaller the number of data involved the greater the probable error. The probable error is written with a combined plus $(+)$ and minus $(-)$ sign $(\pm)$, and represents the true correlation as falling somewhere, either above or below the calculated correlation, by a difference most probably equal to the value of the probable error. A correlation written $.7500 \pm .0600$ indicates that there is an even chance that the true value lies between $.7500 + .0600$, or .8100, and $.7500 - .0600$, or .6900. To be significant, the coefficient of correlation should be at least about four times its probable error. When it is less than this the correlation approaches zero in its significance and is of importance primarily as showing whether a relationship is positive or negative. In discussing the probable error Yule (*36, p. 311*) says:

> If an error or deviation in, say, a certain proportion p only just exceed the probable error, it is as likely as not to occur in simple sampling; if it exceed twice the probable error (in either direction), it is likely to occur as a deviation of simple sampling about 18 times in 100 trials—or the odds are about 4.6 to 1 against its occurring at any one trial. For a range of three times the probable error the odds are about 22 to 1, and for a range of four times the probable error

142 to 1. Until a deviation exceeds, then, 4 times the probable error, we cannot feel any *great* confidence that it is likely to be "significant."

To reduce the labor of calculating these data, in many cases the original data were coded so that all might be included in 10 classes; this was done so that the calculations could be made on sorting and tabulating machines. Because of this grouping many of the coefficients of correlation are smaller than they would have been had the original grouping been retained. In several cases calculations were made by both methods; the difference in results was in some cases as much as 5 per cent. In no case is this difference sufficient to invalidate the results, and, in fact, the results obtained from coding into 10 groups are somewhat safer, since they tend to give a smaller correlation.

Many of the coefficients of correlation shown in Tables 2 and 5 have no direct bearing upon the problem, and therefore are not discussed in this bulletin. They are given, however, to the end that partial correlations between any combination of factors may be calculated. It will be seen that high correlations may exists between variables having no direct relationship. In Table 2, for example, there is a coefficient of correlation of .5510 between the net gain and the average temperature of the night following. Obviously the temperature of the night can not affect the preceding day's gain; the correlation exists, nevertheless, owing to the combination of influences of the causative factors upon both the net gain and the temperature on the following night.

METHOD OF PRESENTING DATA

The graph in Figure 2 represents the manner in which the changes in colony weight during the 24 hours are classified to secure tangible and significant figures as a basis for all calculations. *A* is a fixed point which, on the vertical scale, represents the weight of the colony at 5 a. m. each day in the month of May. Loss of weight caused by departure of bees for the field begins at about this hour, sometimes earlier and sometimes later, but a weight taken at 5 o'clock constitutes a suitable average, since 4 o'clock is too early and 6 o'clock is too late for such a start. For the fall honey flow the whole graph is shifted one hour later, to adapt it to the shorter days, placing *A* at 6 o'clock. *B* is at the point denoting the lowest weight reached during the day and the hour at which this occurs. Although it may occur either in the morning or in the afternoon, the diminution in weight from *A* to *B* is called the *morning loss*, because this loss always precedes the day's gain in weight. This morning loss is due to the bees leaving the hive in flight. Morning loss may be graphically represented by a vertical line equal on the scale chosen to the diminution in weight, and will throughout this bulletin be designated by this name. *C* represents in both weight and time the point at which the colony regains its original morning weight. *D* represents in weight and time the turning point at which the colony has ceased to gain and begins to lose weight. The net gain for the day is therefore represented by a vertical line equal according to the scale to the difference in weight between the early morning reading (at *A*) and the weight reading at *D*. The latter point has not necessarily a fixed hour. The vertical distance between the weight coordinates of *D* and of *E* represents the *nocturnal loss* due to evaporation and consumption for colony maintenance. *E* is, of course, located on the time scale 24 hours after *A*, and becomes the starting point (*A*) for the following day. The only two points which are fixed with regard to time are therefore *A* and *E*. In all diagrams except Figure 2 the base line is drawn, not from the point denoting the weight at the starting point (*A*), but from a zero point raised by an amount equal to the loss in weight between 4 and 5 (or, in the fall, 5 and 6) o'clock. This is done to show more clearly in the graphs the time when loss of weight of the hive actually begins, as the bees begin flying in the morning. Calculations of all data were, however, based on zero at the point *A* (actual weight at 5 or 6 o'clock). Nowhere in the calculations can allowance be made for consumption for colony maintenance, which remains an unknown factor. The gains during the day would be more, and the evaporation loss at night would be less, if this factor could be known.

The name "*midday decline*" is given to the decline in the amount of gain from hour to hour occurring near midday. Although gains are actually taking place during this period on most days, there is a noticeable difference in the rate of gain at this time as compared with that of the hours immediately before and after.

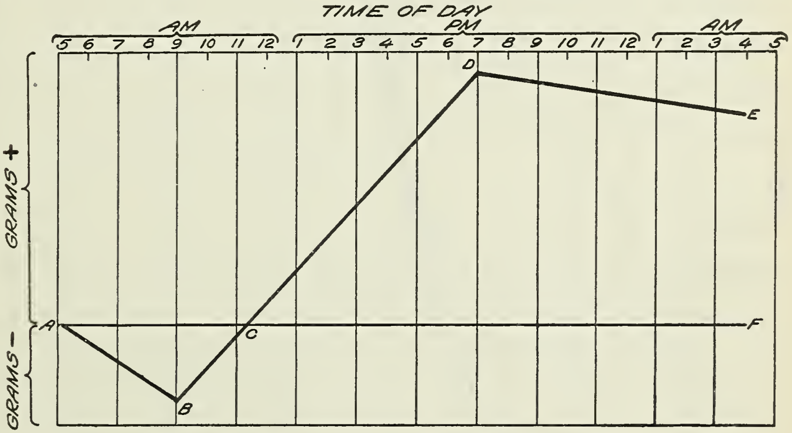

FIG. 2.—Division of changes in the weight of a colony of bees

The 24 hours of the day are divided into diurnal and nocturnal periods, and the designations a. m. and p. m. are not used, since they have no biological significance. The differentiation of diurnal from nocturnal in this discussion is dependent upon the activity of the bees and not on light or darkness. The diurnal period ends and the nocturnal period commences when the weight of the colony ceases gaining, toward the close of the day, and the diurnal period begins, not necessarily at dawn, but at the hour when bee activity outside the hive becomes noticeable. Obviously, flight in the afternoons may be prevented or reduced by rain or inclement weather; and, to prevent the necessity of discarding data obtained on such days, the point *D* is located in the calculation of the data for 1922 at the time when bees cease gaining and begin to lose on the days immediately preceding and following the days in question,

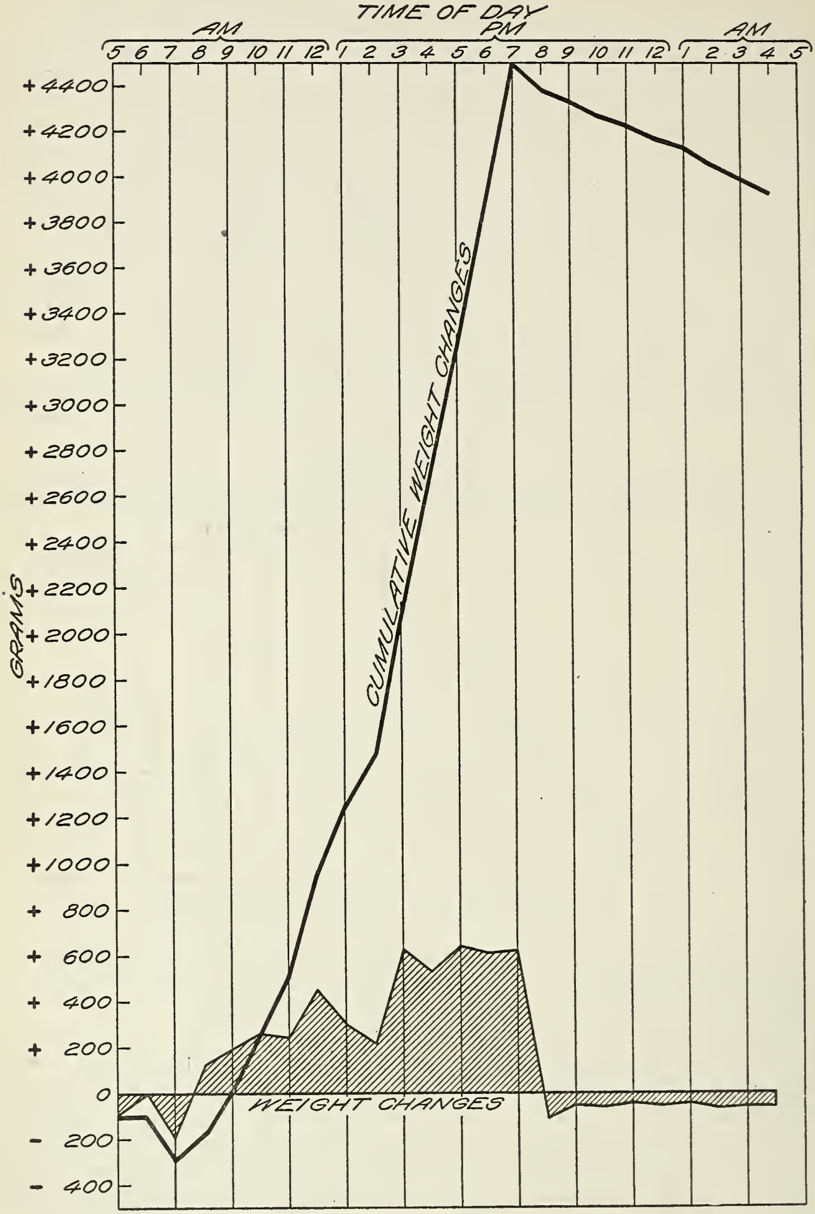

FIG. 3.—Graphs indicating changes of weight in colony *AB*, May 22, 1922. The solid line shows the cumulative weights; the shaded areas the variations in weight from hour to hour

thus making the diurnal and nocturnal periods of approximately equal length for all days studied for that year. This change was necessitated by the errors in weight due to water standing on the hives that year, as previously explained. In calculating the data for 1923 such a shifting of *D* was unnecessary, since the two hives used that year were under cover and no water stood on them. When rain interfered with flight during midday, and flight was later resumed, the point *D* takes its natural place at the close of flight activity for the day.

A graphic representation of changes in weight for a period of 24 hours is given in Figure 3. Either of two methods may be employed, both being shown in this graph. The heavy dark line represents cumulative gains and losses in weight, while the shaded portion shows differences in weight from hour to hour. In case of the shaded portion that part above the base line (shown as *AF* in fig. 2) is increase in weight and that below is decrease. It is readily seen that the shaded portion of the graph is more important than the line showing cumulative gain, since it magnifies small changes in the rate of gain or loss which might otherwise not be observed. For this reason the method showing differences in weight from hour to hour has been used in all graphs except those showing the net gain. In certain graphs both methods are used for greater clearness of differences. The effects of the various weather factors upon the hive-weight changes in the spring and fall are so different that these two periods must be considered separately.

COMPARISON OF CHANGES IN WEIGHT OF TWO COLONIES OF BEES

Beekeepers often assume great differences in the gathering ability of colonies of bees in the same apiary and under exactly similar external conditions. In the interpretation of the data obtained in this investigation it might be assumed that the colonies used were either unusually good or unusually poor at gathering nectar and pollen. In order to show that in the following calculations the individual characteristics of the colonies play a very minor rôle, it seems best at this point to insert a correlation of the changes in weight of the two colonies used in 1923. There is, in fact, little reason to believe that such differences in colonies as have been assumed by many beekeepers actually are important in considering the differences in honey crops obtained by various colonies in an apiary, and this is especially the case when observations are confined to a single race of bees, as was true in this experiment. When differences in the total acquisition of adjacent colonies of bees are noted, they must in most cases be attributed to differences in manipulation or care of the colonies, or to tendencies to retard gathering in certain cases because of crowding, or to a dominance of the swarming instinct, rather than to propensities for heavy or light gathering by the individual bees. Obviously, in the case of poor queens which are unable to keep up the population of their colonies there will be a reduction in the accumulation of stores of the colonies headed by such queens, merely because of lack of sufficient bees; but this does not indicate any reduction in the propensities to gather of the individual bees. Merrill (*24*) reaches the same conclusion in his study of changes in colony weight. Whatever slight differences occur in the propensity of individual bees or colonies of bees to gather nectar and ripen honey are presumably due to actual anatomical differences rather than to marked differences in instinctive activities.

Table 1 gives the hourly changes in weight of colonies 1 and 2 for 13 consecutive days in 1923. The two colonies respond to external stimuli with remarkable similarity hour by hour. Every break in the weight graph of one colony is almost exactly duplicated in that of the other. Figure 4 represents graphically the weights of colony 1 superimposed on those of colony 2 for May 1 and May 22. The hourly differences in weight between the two are practically identical. So far as the amount of gain is concerned, colony 2 is the stronger, but the two behave almost the same from hour to hour. Figure 5 represents the average changes in weight hour by hour for the three colonies (one in 1922 and two in 1923) during the May honey flow. The similarity of these changes in weight of the three colonies is strikingly apparent, despite the fact that the data of colony *AB* were collected in May, 1922, and those of colonies 1 and 2 in May, 1923.

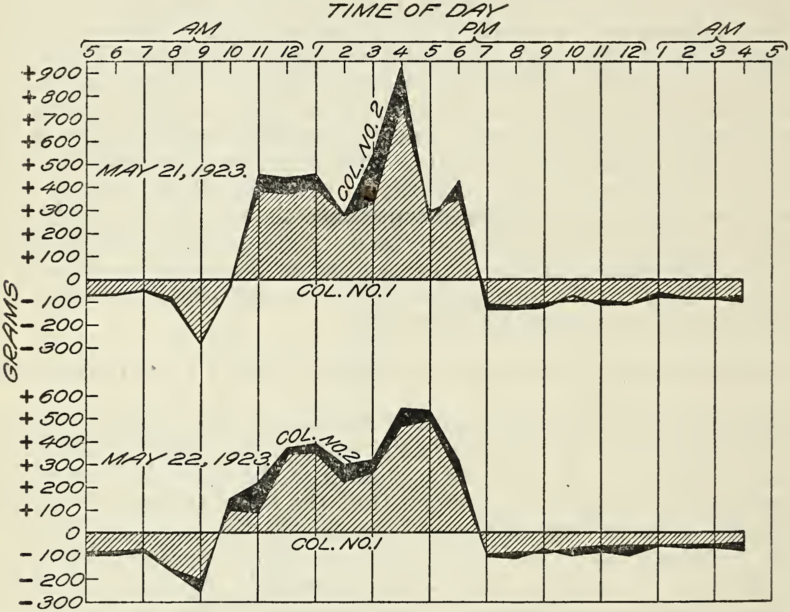

FIG. 4.—Hourly changes in weight of colonies 1 and 2, May 21 and 22, 1923. The shaded portion represents the gains and losses of colony 1 superimposed on those of colony 2. The black areas show the excess of the gain or loss of colony 2 over that of colony 1. (From Table 1.)

TABLE. 1.—*Hourly changes in weight, in grams, colonies 1 and 2, May 18 to 30, 1923*

Date	Colony number	5 a. m.	6 a. m.	7 a. m.	8 a. m.	9 a. m.	10 a. m.	11 a. m.	12 m.	1 p. m.	2 p. m.	3 p. m.	4 p. m.
May 18	1	−20	−40	−150	140	250	270	290	230	50	330	150	400
Do	2	−40	−30	−180	−160	390	420	360	300	80	490	280	560
May 19	1	−60	−30	−80	−200	−130	80	320	280	170	210	370	350
Do	2	−40	−40	−110	−210	−190	140	330	330	130	340	480	420
May 20	1	−70	−60	−90	−180	0	250	280	430	310	220	310	760
Do	2	−80	−100	−100	−190	90	300	300	460	590	80	460	940
May 21	1	−70	−70	−50	−80	−280	−40	380	370	400	270	330	770
Do	2	−70	−70	−50	−90	−280	−30	460	440	460	270	530	920
May 22	1	−80	−80	−70	−160	−200	100	90	340	350	220	260	470
Do	2	−90	−90	−80	−170	−250	150	220	370	390	300	320	540
May 23	1	−50	−60	−70	−80	−220	230	−90	280	390	320	−60	−10
Do	2	−60	−70	−80	−80	−230	300	90	330	370	340	−80	−90
May 24	1	−30	−30	−50	−70	−110	140	360	330	0	400	430	450
Do	2	−40	−40	−60	−50	0	150	510	370	80	430	510	510
May 25	1	−60	−30	−60	−120	170	450	340	370	120	140	250	480
Do	2	−60	−50	−60	0	150	490	400	430	140	290	330	700
May 26	1	−50	−60	−80	50	170	330	530	290	120	30	240	500
Do	2	−60	−80	−50	140	190	330	450	380	60	190	450	660
May 27	1	−50	−50	−20	220	230	350	370	330	360	100	290	480
Do	2	−70	−70	50	340	200	340	410	370	240	30	420	560
May 28	1	−60	−50	−50	−60	20	130	270	300	520	100	170	580
Do	2	−60	−70	−70	−30	50	130	280	250	400	−40	250	660
May 29	1	−70	−50	−30	130	190	300	370	360	390	140	230	540
Do	2	−80	−80	10	210	150	210	240	370	300	50	120	650
May 30	1	−70	−70	−70	−80	−50	−60	40	30	200	180	130	230
Do	2	−60	−60	−80	−40	−330	150	30	140	190	180	100	190

Date	Colony number	5 p. m.	6 p. m.	7 p. m.	8 p. m.	9 p. m.	10 p. m.	11 p. m.	12 p. m.	1 a. m.	2 a. m.	3 a. m.	4 a. m.
May 18	1	470	210	−70	−50	−80	−60	−50	−50	−60	−50	−50	−70
Do	2	660	360	−50	−50	−70	−70	−70	−50	−60	−50	−50	−70
May 19	1	360	590	130	−100	−100	−90	−80	−100	−60	−70	−40	−80
Do	2	470	710	280	−110	−100	−80	−80	−100	−60	−60	−40	−70
May 20	1	370	−130	−120	−70	−70	−60	−70	−90	−70	−60	−80	−70
Do	2	270	−130	−110	−90	−60	−80	−70	−70	−70	−70	−60	−80
May 21	1	290	350	−110	−120	−100	−90	−90	−110	−60	−80	−80	−70
Do	2	250	430	−130	−130	−120	−70	−110	−110	−70	−80	−80	−90
May 22	1	490	240	−90	−80	−80	−70	−60	−60	−60	−60	−60	−50
Do	2	530	310	−100	−110	−70	−90	−80	−100	−60	−70	−70	−80
May 23	1	140	90	−60	−20	−50	−30	−40	−20	−40	−20	−30	−30
Do	2	180	160	−50	−40	−70	−30	−60	−30	−40	−40	−40	−40
May 24	1	460	370	−30	−70	−60	−70	−50	−50	−40	−50	−40	−50
Do	2	550	560	−30	−110	−60	−100	−40	−80	−60	−80	−60	−60
May 25	1	400	400	70	−100	−90	−60	−70	−60	−50	−50	−50	−50
Do	2	580	560	−140	−130	−100	−80	−90	−90	−70	−70	−70	−80
May 26	1	400	480	360	−90	−70	−80	−50	−80	−50	−50	−50	−60
Do	2	550	640	440	−100	−90	−90	−80	−110	−60	−80	−80	−80
May 27	1	400	520	510	−100	−80	−90	−80	−80	−60	−60	−60	−60
Do	2	410	540	530	−90	−90	−100	−80	−120	−70	−60	−80	−70
May 28	1	560	750	490	−90	−100	−80	−70	−90	−60	−70	−70	−70
Do	2	610	760	450	−80	−100	−90	−60	−120	−70	−60	−80	−70
May 29	1	690	680	620	−80	−120	−80	−80	−110	−70	−70	−80	−80
Do	2	580	580	550	−80	−120	−60	−80	−110	−60	−60	−90	−80
May 30	1	520	710	150	−80	−80	−70	−50	−70	−50	−50	−50	−50
Do	2	440	620	140	−100	−50	−60	−50	−90	−30	−50	−60	−50

The coefficient of correlation of the changes in weight between colony 1 and colony 2 for the diurnal hours from 6 a. m. to 7 p. m., inclusive, based on 277 hours, is .9076 ± .0071. The coefficient of correlation for the nocturnal hours, 8 p. m. to 5 a. m., inclusive, based on 190 hours, is .8938 ± .0098. The correlations are high, and have an insignificant probable error, indicating that the activity in both colonies was chiefly determined by factors other than internal ones. The differences observed between these two colonies were almost exclusively the actual differences of loss or gain, and the most probable explanation of these differences is to be found in the presumably smaller number of bees in colony 1. Actual counts of the bees of the two colonies could not be taken without vitiating the experiment. If any structural difference existed between the bees of the two colonies (as assumed by Merrill in his work), this was not determined, and with such high correlations as occur in the changes in weight of these two colonies such an explanation seems improbable. The high correlations do not indicate that any important internal difference, as in the condition of the queen, or the age of the bees, existed between the colonies. If there had been such differences so high a correlation would not have existed. It must be kept in mind that both colonies were amply supplied with storage and evaporating space.

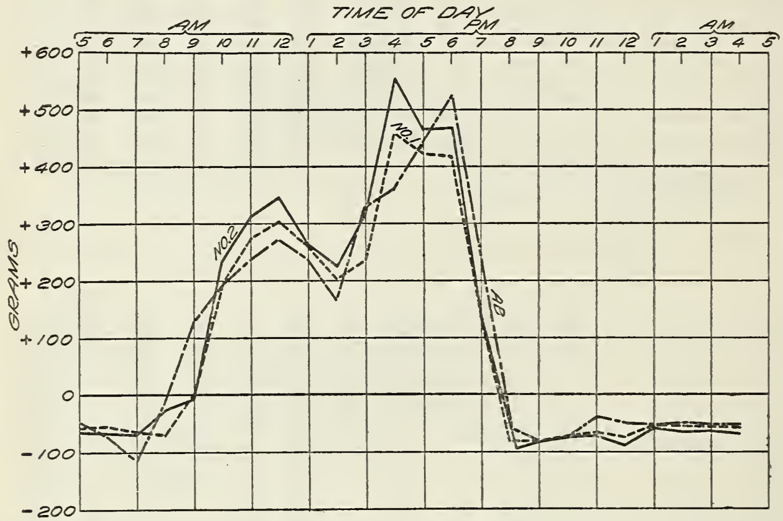

FIG. 5.—Graphs of the average variations, hour by hour, in the weight of Colonies 1, 2, and *AB* for the May honey flow. Note the minimum of the midday decline at 2 o'clock for the three colonies

If one of the colonies had been crowded for space, and this had interfered with the work of gathering, undoubtedly the coefficient of correlation would have been smaller.

An examination of these data indicates that the field forces of the two colonies were working at approximately maximum efficiency. The two colonies gathered a total crop for the year 1923 which compares favorably with that of any other colonies kept in the general locality. An examination of the striking similarity of the changes in weight of the two colonies at the time when both regained their morning weight and at the time of the midday decline of increase in weight strongly suggests that both colonies were gathering all the nectar which was available for them, in proportion to the number of bees available in each for field activity. This similarity is brought out much more clearly in the averages for the entire May honey flow (fig. 5) than in those for individual days (Table 1), since toward the close of the honey flow colony 1 was apparently increasing in numbers more rapidly than colony 2. If it is assumed that both colonies were working at almost maximum efficiency, the midday decline in the rate of increase in weight to some extent agrees with Bonnier's statements (*1*) that less nectar is available early in the afternoon than earlier or later. Unless there exists some unknown influence on bee behavior at the time of the midday decline, it must be believed that the reduction in the rate of the increase in weight at this time is due to a reduction in the amount of nectar in the honey plants. Surrounding the Bee Culture Laboratory there is a vast acreage of tuliptrees, and there are comparatively few bees in the neighborhood other than those of the bureau apiary. Bonnier's assertion that bees carry partial loads of nectar when nectar is scarce is thus more probable, although the explanation may lie in the necessity for trips of longer duration at this time. There is no reason to believe that the bees actually gathered every drop of nectar available in the neighborhood at the time of this decline.

THE SPRING PERIOD

As has been stated, the data used in a consideration of the spring and fall honey-flow periods are not entirely comparable, since for the spring honey flow the only records used are those for days which show a net gain of at least 980 grams, whereas in the case of the fall honey flow the record for every day from September 4 to October 5 is used. Furthermore, the spring honey flow is much more intense in the vicinity of the laboratory than is that of the fall. For these reasons it seems best to consider the two periods separately. In the discussion immediately following, the various phases of the changes of weight during the day are taken up for the spring period, covering the time when the tuliptree was in bloom.

MORNING LOSS

Figure 3 illustrates the changes in weight during a typical day of the spring honey flow. In this case the morning loss is small and covers the time from 5 a. m. to 7 a. m., the majority of this loss occurring during the last hour. Usually the morning loss is quite small and rarely continues more than three or four hours. The amount and duration of the morning loss undoubtedly depend largely upon the proximity of nectar-producing plants and the abundance of their secretion, and upon weather factors prevailing at this time of the day. On some days the morning loss is negligible and scarcely distinguishable from the nocturnal loss, as on May 27 and 29, 1923 (fig. 6, *b*). The bees began to return to the hive almost immediately on these days, and thus with their increased weight more than compensated for the loss during the early morning hours. It is quite evident that on such days nectar was abundant and within easy reach of the bees.

The coefficient of correlation between morning loss and net gain is −.6350±.0652. This indicates that the smaller the morning loss the greater the resulting gain, and emphasizes the importance of locating an apiary as near as possible to the principal sources of nectar. The significance of morning loss will become more apparent later, in the consideration of the fall period.

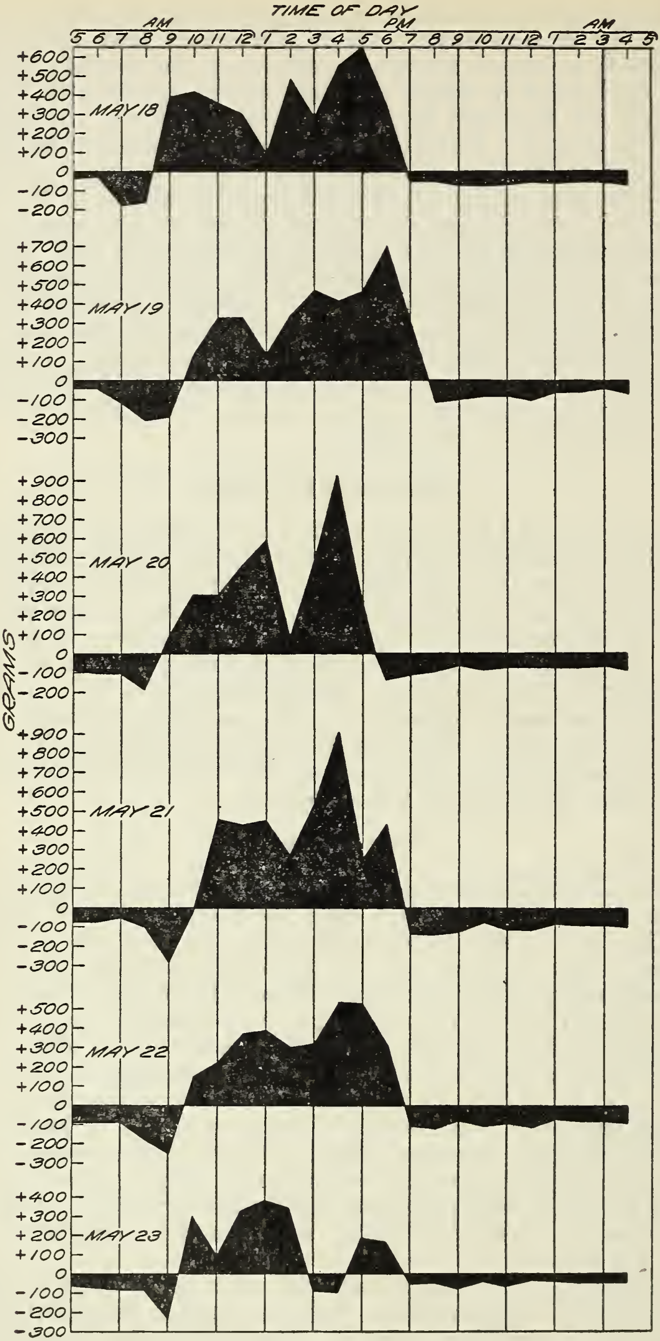

FIG. 6 (*a*).—Daily graphs for six consecutive days of colony 2, showing hourly changes in weight (see Table 1)

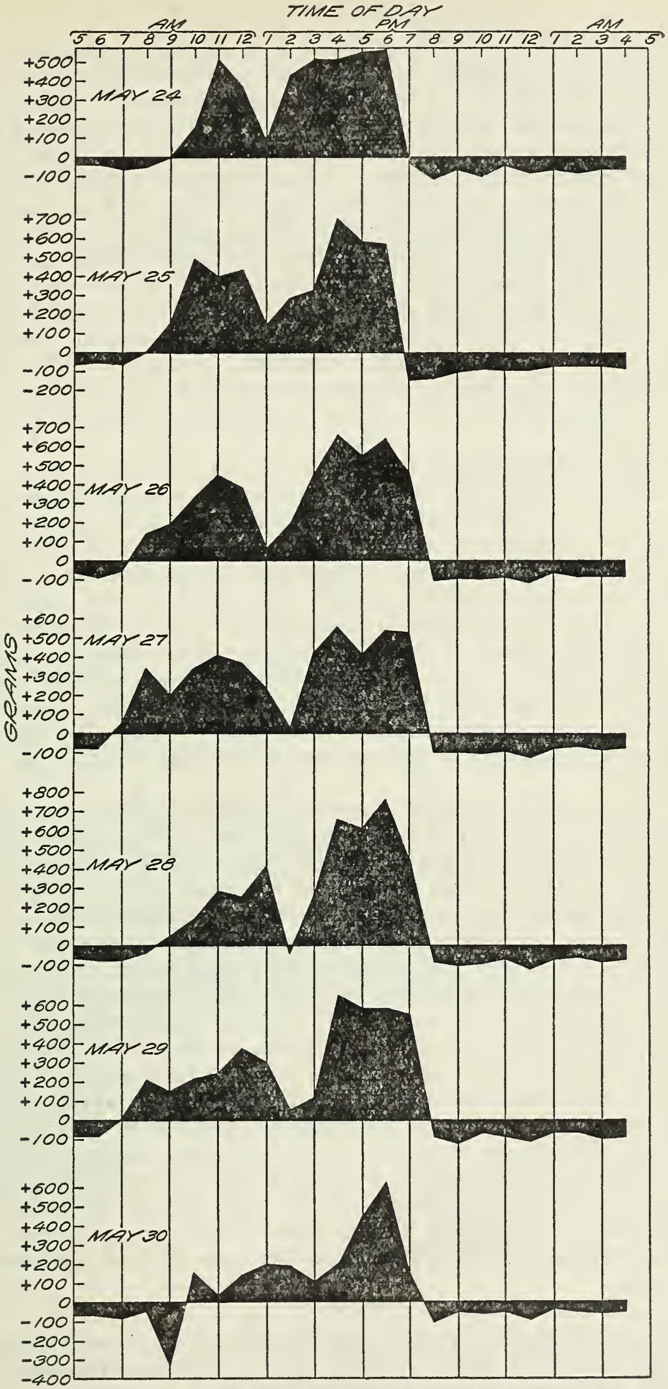

FIG. 6 (*b*).—Daily graphs for seven consecutive days of colony 2, following those of Figure 6 (*a*), showing hourly changes in weight (see Table 1)

MIDDAY DECLINE IN RATE OF GAIN

During the period of spring honey flow, after the morning loss in weight has ceased, which may occur at any time between 6.30 and 10 a. m. (the average hour for 1922 was 8 a. m., and for 1923 9 a. m.), the colony increases in weight with a more or less regular acceleration until midday. At this time a decided slackening usually occurs in the rapidity of gain in weight. This change in rate of gain is surprisingly constant in the time of its appearance and can be distinguished during practically the whole of the spring honey flow. The minimum rate of gain in weight, after gains have been established in the morning, usually comes at about 1 or 2 o'clock in the afternoon. On some days this decrease in rate of gain is decided, while on other days it is scarcely noticeable. When actual changes in weights are plotted this midday decrease in rapidity of gain can scarcely be seen, but when the data are plotted so as to show differences in weight from hour to hour it becomes quite obvious (figs. 3, 7, 8).

The cause of this change in rate of gain at midday is not entirely clear. Dufour (*10*) in his records mentions a similar phenomenon, and Bonnier (*1, p. 163*) connects a decrease in the amount of available nectar with low relative humidity and high temperatures prevailing at the same time of day. Bonnier measured the amount of nectar produced at various hours and found that less nectar is produced toward the middle of the day, when high temperatures and low relative humidities are usually encountered. He further found that at this time bees return to the hive with less than their maximum loads, and that fewer bees leave the hive for the field during this midday period, in comparison with periods before and after. Either of these two facts might be sufficient to account for the midday decline in rate of gain.

Figure 5, as stated, shows the average hourly changes in weight for colonies 1, 2, and *AB* for the spring honey flow. The similarity in the graphs for colonies 1 and 2 is not surprising, since these colonies were side by side and each was stimulated by exactly the same outside factors. The graph for colony *AB*, however, represents the changes for a colony one year earlier, but it closely follows the others. The midday decline in rate of gain is prominent in all three, and, although differing in magnitude, the three are intimately similar from hour to hour. The graphs for average temperature, relative humidity, and hours of sunshine bear no visible relation to the break in the three graphs showing gain and loss. The maximum temperatures for both years come later in the day than the midday decline, and the minimum relative humidity occurs at an hour slightly preceding. Until further investigations are made, Bonnier's (*1, p. 164*) observation of decreased nectar secretion on the part of the plant and the resulting effect on bee behavior must be accepted as the most logical explanation of this phenomenon, although the reasons which he gives for these changes on the part of the plants and the bees do not seem entirely satisfactory.

NET GAIN

The midday decline in rate of gain is included as part of the net gain, since an actual loss rarely occurs at this time during a good honey flow. The 13 graphs in Figure 6, for as many days, show sharply how decidedly the midday decline reduces the amount of net gain. If the gaps caused by the midday decline were bridged the net gains would be appreciably larger. By theoretically bridging together the two peaks of the graphs of hourly gain, and thus eliminating the midday decline in rate of gain, the net gain for colony *AB* is increased 15.72 per cent. The net gains of colonies 1 and 2 are similarly increased 16.35 per cent and 16.95 per cent, respectively, so that in the years recorded the midday decline caused a loss of from 15 to 16 per cent in the net gain for the day.

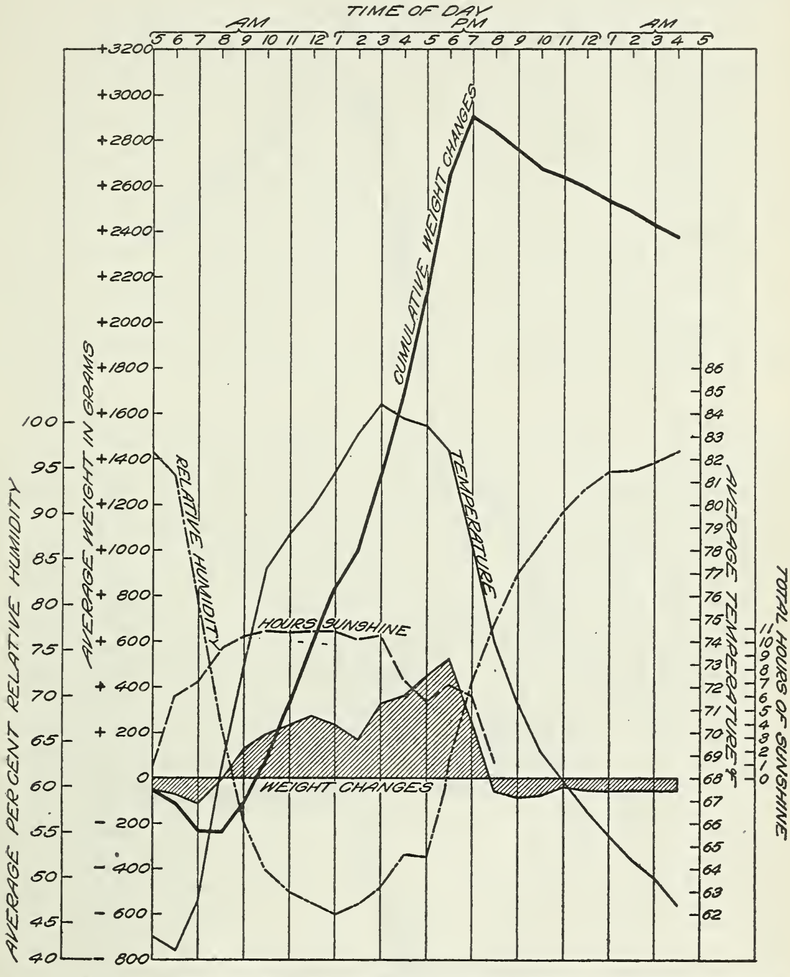

FIG. 7.—Graphs of average hourly weight changes, temperature, relative humidity, and total hours of sunshine. Colony *AB*, spring period

Actual gains in weight do not occur immediately after the sun rises, but they do cease almost as soon as the sun goes down, as shown in Figures 7 and 8. Although bees make actual gains in hours recorded as cloudy, it is interesting to note that in 1922 the actual hours of sunshine during the spring honey flow totaled 124.4, while increases in weight were recorded during 136.4 hours. In May, 1923, during the honey flow there were 138.5 hours of sunshine, while colony 2 made gains during 137.5 hours. The similarity between the hours of sunshine and hours in which gains were made are somewhat of a coincidence, for, as stated, gains are sometimes made in cloudy hours and gains are not made in all hours of sunshine. The effect of sunshine upon net gain will be discussed later (p. 36).

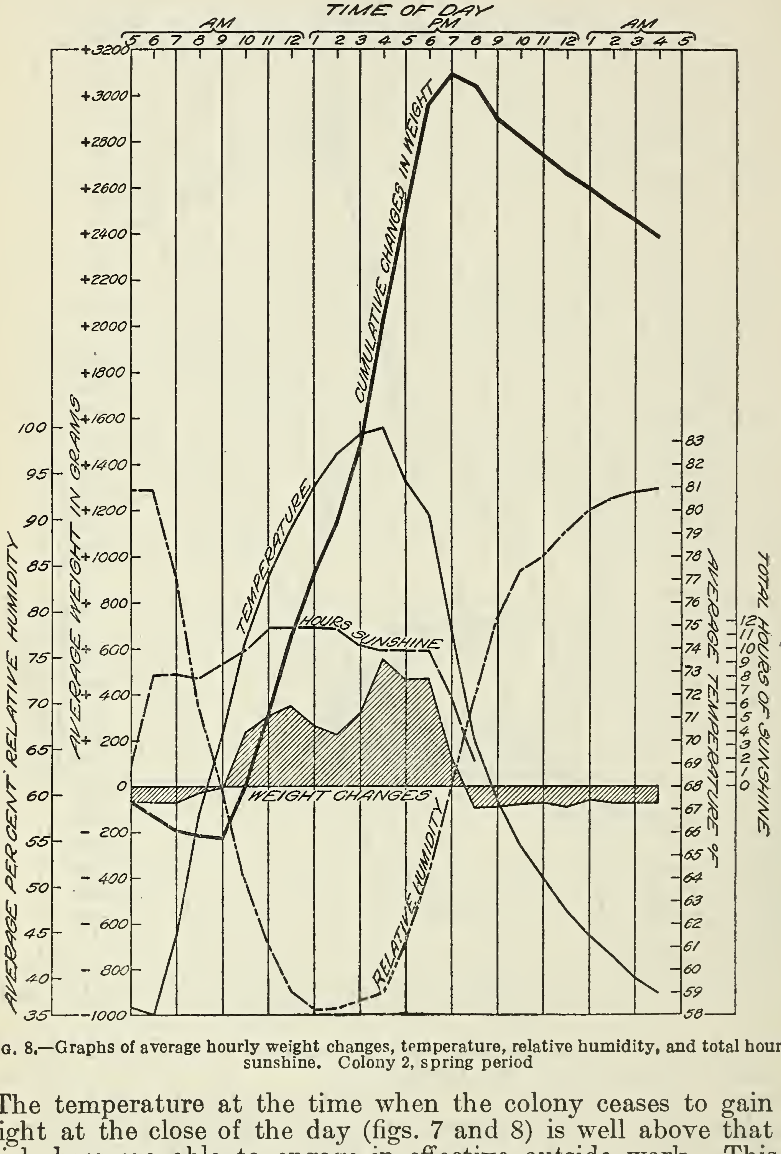

FIG. 8.—Graphs of average hourly weight changes, temperature, relative humidity, and total hours of sunshine. Colony 2, spring period

The temperature at the time when the colony ceases to gain in weight at the close of the day (figs. 7 and 8) is well above that at which bees are able to engage in effective outside work. This is shown by the fact that the average temperatures at the time of the morning loss, due to flights, are much lower than the temperatures at the time that flights cease. The daily gains generally end abruptly, a fact suggesting that the bees do not desert the field at this time for lack of nectar.

NOCTURNAL LOSS

The nocturnal loss is calculated from the time that gain ceases until the bees leave for the field the following morning (fig. 2, D–E). Nocturnal loss is largely the result of the evaporation of water which is given off in the process of ripening honey. In this regard, nocturnal loss bears an intimate relation to the net gain.

The coefficient of correlation between noctural loss immediately following the day's gain and the net gain is .4112 ± .0909. The correlation of the diurnal gain with the loss of the second night following is much less, being .1890 ± .1099. In the second instance the coefficient of correlation is not twice its probable error, and so can not be considered as especially significant. This would indicate that the greater part of the necessary evaporation is accomplished during the first night and that little is left over until the following night. Evaporation naturally begins almost as soon as nectar is gathered, and therefore occurs during the day of gathering and probably during the following day, but in neither case is it possible to determine the amount of evaporation by day from a record of colony weights.

In 1923, colony 1, from May 18 to May 30, lost during the nights 25.29 per cent of the total amount gained. Colony 2 in the same period lost 24.69 per cent of the total gain. For 11 days in May, 1922, colony *AB* lost during the nights 17.85 per cent of the total gain. This lower percentage of loss in 1922 may have been occasioned by the character of the nectar collected, since considerable locust honey was available. It is also well known that the water content of nectar varies from year to year with different varieties of plants and with climatic factors. A calculation of Dufour's (*11*) data shows a loss of 26.16 per cent for 14 consecutive nights in May and June, when the minimum net gain was 970 grams, and the coefficient of correlation between net gain and nocturnal loss for this period is found to be .6663 ± .1002. Maujean (*23*) found a nocturnal loss of 22.53 per cent of the net gain during the honey flow of 1905, and a loss of 27.40 per cent during that of 1904. A calculation of Maujean's data shows a coefficient of correlation of .7868 ± .0411 between the net gain and the following night's loss, a correlation of .5319 ± .0795 between the daily net gain and the loss of the second night following the day concerned, and of .2813 ± .1035 between net gain and the loss of the third night following. These results would indicate that in this particular instance evaporation was practically complete by the end of the third night; a much slower evaporation than seems to have occured in the present investigation. Hommell (*18*) states that according to Sylviac seven days is the minimum observed time required to change nectar completely to the consistency of honey; he thinks, however, that seven days is entirely too long for this minimum period, and points out that de Layens long ago discovered that in warm and dry weather nectar may be of such consistency as to permit almost immediate capping by the bees. Hommell points out that Huillon likewise gives a much shorter period for the completion of evaporation, and states that beekeepers can remove honey during the morning following a heavy honey flow without much danger that the honey will be too thin, since the greater part of the evaporation takes place during the first night.

The strength of the colony must likewise be an important factor in the rate of evaporation. While it is true that a weak colony collects less nectar than a strong one, it does not follow that the efficiency of the two colonies is proportional to their strength.

In studying the correlations in Table 2 it is seen that the external factors have but little influence on nocturnal loss. If there existed a strong internal individual influence in either one of these colonies, one would not expect such a high correlation between the nocturnal losses of colonies 1 and 2 (.8938, see p. 13). If external factors are important so far as nocturnal loss is concerned they must be other than temperature, temperature variation, relative humidity, or variation of relative humidity. Again the need for strong colonies is apparent. Weather conditions at night undoubtedly influence weak colonies to a greater extent than they do strong ones. Phillips and Demuth (*30*) in their wintering experiments have shown the detrimental effect of low temperatures upon weakened colonies, while strong colonies reacted normally to the same temperatures, if we take the survival of strong colonies and the death of weak ones as a criterion for differences in normal behavior.

THE FALL PERIOD

The data upon which the calculations for this period are based were secured from September 4 to October 5, 1922, during the period of the fall honey flow. No criterion for minimum gain was used in selecting the day to be correlated, and all days irrespective of gain or loss are included in the calculations. For this reason the figures can not be compared directly with those of the spring period, when only days having a minimum of 980 grams were selected. In studying the figures representing days of the fall period, it will be seen that the graphic presentations of hive weights are more significant than graphs showing the difference in weight from hour to hour. As in the analysis of the hourly weight changes of the spring period, weather factors, as they affect changes of weight in the fall, will be postponed for later discussion.

MORNING LOSS

The relation of morning loss to net gain appears to be the reverse of what it is during the spring period. The correlation between morning loss and net gain is .5769 ± .0825, so that not only is the correlation between these two factors numerically greater than it is in the spring, but it is positive rather than negative. The morning losses generally were heavy, being from 390 to 1,690 grams. The morning loss is primarily brought about by the rapid exit of bees, as undoubtedly the returning bees with their loads of nectar more than make up for the loss due to the consumption of stores for maintenance of the colony, which constitutes a steady loss at all times. The duration of these losses varied from four to nine hours, and often equally as long a time would be required for the colony to regain its original weight of the early morning, this in turn leaving only

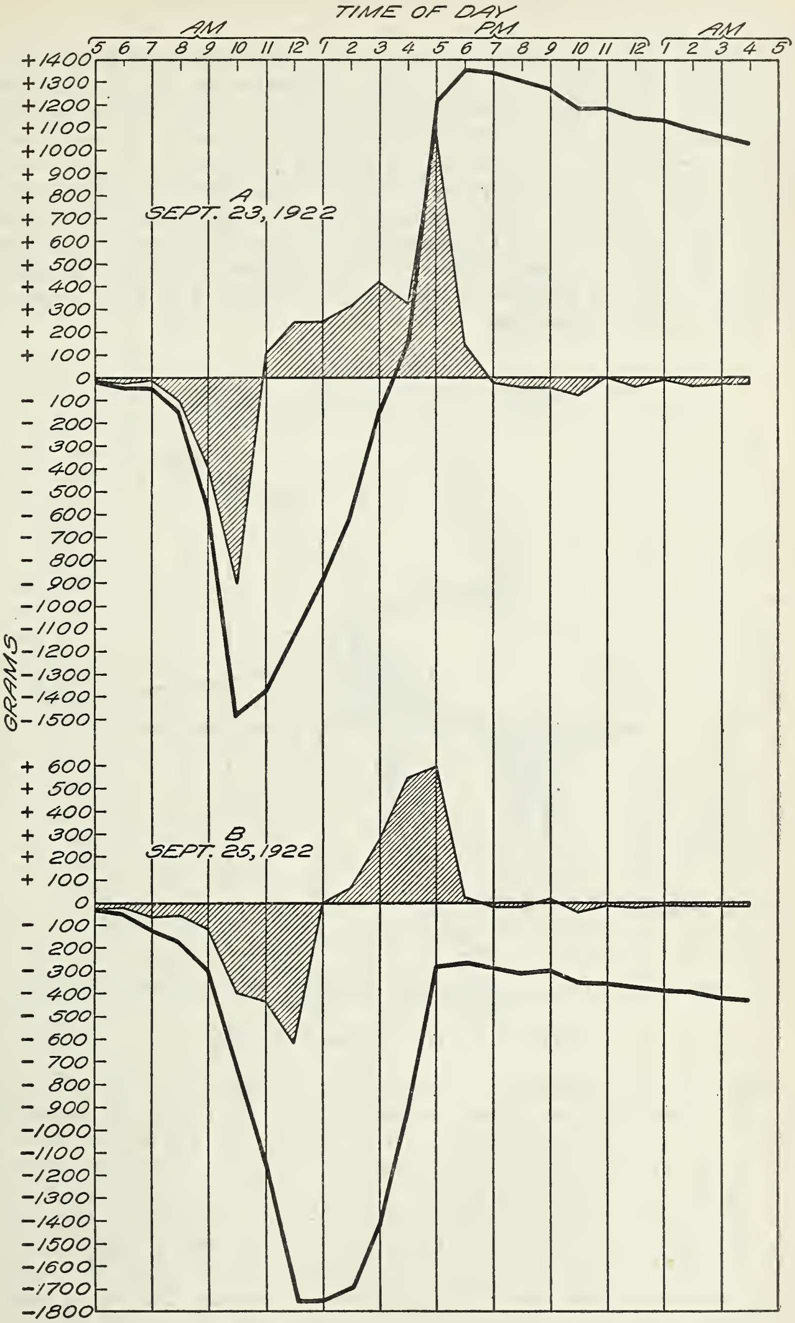

FIG. 9.—Hourly changes in weight of colony *B;* A, September 23, B, September 25, 1922

a few hours at the close of the day for the accumulation of net gain.

On September 25, 1922, colony B sustained the maximum morning loss of the season (fig. 9). The energy expended by the bees on this day, from the beekeeper's point of view, was misappropriated since the result of the day's labor netted the colony a loss of 255 grams. The weather of this day was ideal in every respect, and the bees evidently searched for nectar but found little or none. The average morning loss of the spring period is insignificant in comparison with that of the fall period. Figure 9 illustrates the magnitude of the morning losses on September 23 and 25, 1922, respectively, while Figure 10 shows the average loss for the entire fall honey flow of that year.

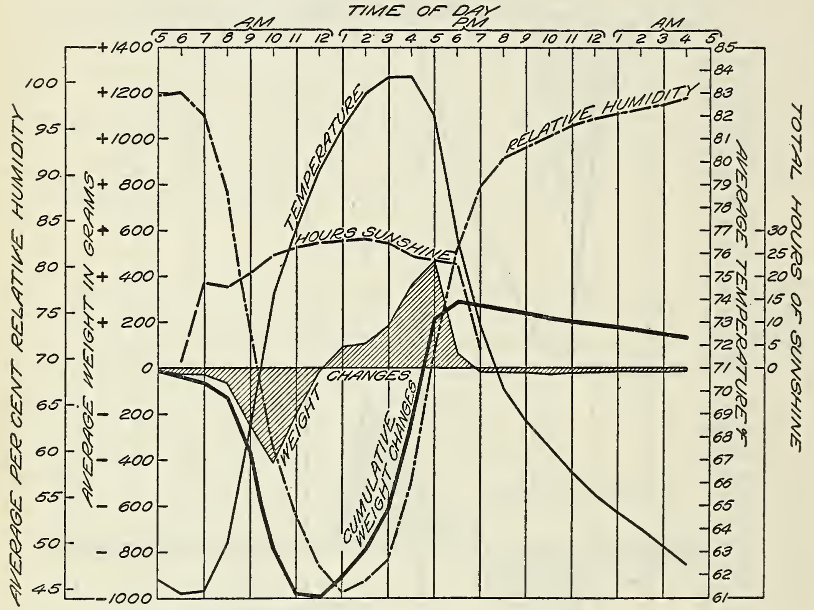

FIG 10.—Graphs of average hourly changes in weight, temperature, relative humidity, and total hours of sunshine. Colony *B*, fall period

MIDDAY DECLINE IN RATE OF GAIN

Although it is possible to distinguish the midday decline in rate of gain in weight during the majority of the fall days, it is seldom pronounced in its character. It is shown in the shaded portion of Figure 10, which presents the average variations in weight for each hour of the day in the fall period. The graphs of actual weights of fall days do not show this midday decline because it occurs so shortly after the time when the colony stops losing weight. The effect of the midday decline, as determined by bridging the gap at this period upon the net gain, is, however, greater than it is during the spring, since in this case the net gain was decreased 50.66 per cent on account of it.

NET GAIN

The net gain is accumulated late in the day. Figure 10 shows that the colony did not regain its original weight until between 4 and 5 o'clock in the afternoon, and since increase stops on the average at 6 o'clock any net gain must be accumulated between these hours. Undoubtedly the nature of the nectariferous plants abounding in any one locality will, together with the prevailing climatic factors, determine the time and amount of gain in weight. An entirely different picture may be expected in the buckwheat regions, since buckwheat is known to secrete nectar only in the forenoon.

Figure 1 well illustrates the vast differences, as shown by hourly changes in the hive weight, that may exist in the interrelationship of nectar-producing plants, bees, and weather factors. The two curves in this figure represent these changes for May 9 (solid line) and September 28 (dash line), 1922. On both of these days the net gain was practically identical, but the activities of the bees in securing this gain were vastly different on the two occasions. On the earlier day the morning loss ceased at 8 o'clock; on the other it continued until 11 o'clock and was more than seven times as great. On May 9 the original weight was regained by 12 o'clock, whereas on September 28 it was not regained until between 4 and 5 o'clock in the afternoon. The comparison of these two days also serves to emphasize the statement made earlier that to be of service weight records must be taken frequently and methodically. If only early morning and evening records are taken nothing can be known as to the time during the day when nectar is being brought into the hive, and, moreover, if the last weight of the day were made an hour or two earlier, one day might show a gain while the other shows a loss.

NOCTURNAL LOSS

The nocturnal loss during the fall is appreciably higher in comparison with the net gain than it is in the spring. For the days showing a net gain in Table 3, the nocturnal loss amounts to 48.72 per cent of the net gain. The correlation between these two is also much higher than it is in the spring, being .8568 ± .0333. A calculation of Dufour's (*11*) data likewise shows a higher correlation between nocturnal loss and net gain for the fall, being .8689 ± .0458, as opposed to a spring correlation of .6663 ± .1002.

A higher correlation between net gain and nocturnal loss, as well as a larger per cent of loss, is naturally to be expected when net gains are small. Such a condition obtains in this case, since a larger part of the nocturnal loss is to be attributed to consumption for colony maintenance.

CORRELATIONS BETWEEN EXTERNAL FACTORS AND THE CHANGES IN COLONY WEIGHT

Having discussed the changes in weight of the colonies during the spring and fall honey flows and the correlations for the various parts of the day, it now is desirable to determine what degree of correlation exists between the changes in weight and the factors of the environment in so far as data are available for computation. These will be discussed in the following order: Temperature, relative humidity, solar radiation, and hours of sunshine. Numerous coefficients of correlation along these lines are presented in Table 2, together with their probable errors.

TABLE 2.—*Coefficients of correlation between changes of colony weight in the spring and various weather factors*

	Net gain	Nocturnal loss	Diurnal average temperature	Diurnal temperature variation	Diurnal average relative humidity	Diurnal relative humidity variation	Hours sunshine	Solar radiation	Nocturnal average temperature	Nocturnal temperature variation	Nocturnal average relative humidity	Nocturnal relative humidity variation
Net gain		0. 4112 ±. 0909	0. 7529 ±. 0473	0. 5967 ±. 0704	−0. 3806 ±. 0935	0. 4229 ±. 0898	0. 6124 ±. 0683	0. 5525 ±. 0760	0. 5510 ±. 0762	0. 2941 ±. 0999	−0. 4495 ±. 0873	0. 0763 ±. 1087
Nocturnal loss	0. 4112 ±. 0909		. 3063 ±. 0991	. 0583 ±. 1090	. 0141 ±. 1093	. 1653 ±. 1064	. 3068 ±. 0991	. 2375 ±. 1032	. 1754 ±. 1060	—. 3439 ±. 0964	—. 1264 ±. 1076	—. 0654 ±. 1089
Diurnal average temperature	. 7529 ±. 0473	. 3063 ±. 0991		. 5717 ±. 0736	—. 1551 ±. 1067	. 3899 ±. 0927	. 5798 ±. 0726	. 4416 ±. 0880	. 7947 ±. 0403	. 2571 ±. 1021	—. 3882 ±. 0929	—. 0157 ±. 1093
Diurnal variation of temperature	. 5967 ±. 0704	. 0583 ±. 1090	. 5717 ±. 0736		—. 7272 ±. 0515	. 7852 ±. 0419	. 7703 ±. 0444	. 6727 ±. 0599	. 3185 ±. 0983	. 3419 ±. 0966	—. 5114 ±. 0808	. 5158 ±. 0803
Diurnal average relative humidity	—. 3806 ±. 0935	. 0141 ±. 1093	—. 1551 ±. 1067	—. 7272 ±. 0515		—. 7584 ±. 0464	—. 6420 ±. 0643	—. 6518 ±. 0629	. 1956 ±. 1052	—. 4264 ±. 0895	. 5833 ±. 0721	—. 7018 ±. 0555
Diurnal variation of relative humidity	. 4229 ±. 0898	. 1653 ±. 1064	. 3899 ±. 0927	. 7852 ±. 0419	—. 7584 ±. 0464		. 6780 ±. 0591	. 6280 ±. 0662	—. 0072 ±. 1094	. 1970 ±. 1051	—. 5344 ±. 0781	. 5294 ±. 0553
Hours sunshine	. 6124 ±. 0683	. 3068 ±. 0991	. 5798 ±. 0726	. 7703 +. 0444	—. 6420 ±. 0643	. 6780 ±. 0591		. 8826 ±. 0241	. 2059 ±. 1047	. 3822 ±. 0934	—. 6445 ±. 0639	. 6343 ±. 0653
Solar radiation	. 5525 ±. 0760	. 2375 ±. 1032	. 4416 ±. 0880	. 6727 ±. 0599	—. 6518 ±. 0629	. 6280 ±. 0662	. 8826 ±. 0241		. 1012 ±. 1082	. 3358 ±. 0970	—. 5308 ±. 0785	. 6258 ±. 0665
Nocturnal average temperature	. 5510 ±. 0762	. 1754 ±. 1060	. 7947 ±. 0403	. 3185 ±. 0983	. 1956 ±. 1052	—. 0072 ±. 1094	. 2059 ±. 1047	. 1012 ±. 1082		—. 0739 ±. 1088	—. 0043 ±. 1094	—. 3373 ±. 0969
Nocturnal variation of temperature	. 2941 ±. 0999	—. 3439 ±. 0964	. 2571 ±. 1021	. 3419 ±. 0966	—. 4264 ±. 0895	. 1970 ±. 1051	. 3822 ±. 0934	. 3358 ±. 0970	—. 0739 ±. 1088		—. 8781 ±. 0250	. 7031 ±. 0553
Nocturnal average relative humidity	—. 4495 ±. 0873	—. 1264 ±. 1076	—. 3882 ±. 0929	—. 5114 ±. 0808	. 5833 ±. 0721	—. 5344 ±. 0781	—. 6445 ±. 0639	—. 5308 ±. 0785	—. 0043 ±. 1094	—. 8781 ±. 0250		—. 6819 ±. 0585
Nocturnal variation of relative humidity	. 0763 ±. 1087	—. 0654 ±. 1089	—. 0157 ±. 1093	. 5158 ±. 0803	—. 7018 ±. 0555	. 5294 ±. 0553	. 6343 ±. 0653	. 6258 ±. 0665	—. 3373 ±. 0969	. 7031 ±. 0553	—. 6819 ±. 0585	

TEMPERATURE AND CHANGES IN THE COLONY WEIGHT

In the vast literature of beekeeping few data are found to be useful in throwing light on the relation of external temperature to the changes in colony weight. Many experiments, however, have been conducted to ascertain the relation of temperature to nectar secretion. Of the latter, the work of Bonnier stands out most prominently. Unfortunately, he published but few of the actual data upon which his conclusions were based, so that it is difficult to make mathematical comparisons with the data herein presented or with the data of other investigators. Broadly speaking, the correlation between plant or animal activity and temperature is positive within, of course, certain limits. Most reactions, whether organic or inorganic in nature, are retarded by low temperatures, and increased by higher temperatures, although there are many examples to the contrary.

TEMPERATURE AND NET GAIN

During the spring period temperature has a marked effect upon net gain, the correlation between these factors being .7529 ± .0473. This is a higher correlation than was found between net gain and any of the other weather factors, from which it appears that among those considered, temperature is the most important single factor influencing changes in the colony weight. Bonnier (*1, p. 163*), in referring to nectar secretion, states that the volume of nectar varies inversely as the temperature. Kenoyer (*20*) also says that the accumulation of sugar in the flower and its vicinity varies inversely as the temperature. In referring to honey production, however, Kenoyer (*19*) states that good honey months average slightly higher in temperature than poor ones, this being especially true of the fall and spring months, and that the yield is best on days having a maximum of 80° to 90° F. (26.7° to 32.2° C.). Ono (*26, p. 15*), in studying the secretion of extrafloral nectaries, does not lay much stress on temperature. He found that within the range of 15° to 25° C. (59° to 77° F.) the influence of temperature upon secretion is not remarkable; and that temperature seems to have merely an indirect influence in so far as it affects the plant itself. Harrault (*15*) states that for a given plant placed in suitable vegetative conditions the production of nectar increases with the increase in temperature and the quantity of sunlight, the production following general botanical laws. The writer's calculation of Harrault's rather scanty data gives a correlation of .5258 ± .0639 between net gain and temperature. A negligible correlation of .0065 ± .1079 was likewise calculated from data presented by Maujean (*23*).

Bonnier reached his conclusion by removing the nectar from various species of plants from hour to hour by means of a small pipette, and noting the temperature. The writer's calculations of Bonnier's data gave a correlation of $-.6581 \pm .0901$ between temperature and nectar secretion. Coefficients of correlations were also calculated from the same data between humidity and gain and between humidity and temperature, with the following results, where T = temperature, H = humidity, and N = volume of nectar:

$$r_{NT} = -.6581 \pm .0901$$
$$r_{NH} = .8040 \pm .0562$$
$$r_{TH} = -.9202 \pm .0243$$

Humidity is, of course, influenced by temperature. In order, therefore, to arrive at a more correct value of the effect of temperature upon nectar secretion, it is necessary to eliminate the effect of humidity by reducing this variable to a constant. This is conveniently done by the employment of the formula for partial correlation—

$$_{H}r_{NT}=\frac{r_{NT}-(r_{NH}\,.\,r_{TH})}{\sqrt{(1-r^2_{NH})\,(1-r^2_{TH})}}$$

Substituting in this formula the above coefficients of correlation, and solving, we find that—

$$_{H}r_{NT}=.3306$$

It seems, therefore, according to Bonnier's data, that when humidity is constant nectar secretion varies directly with temperature.

The interpretation of similar data compiled by other investigators would be highly desirable at this place, so that results could be compared with those of Bonnier. The writer's calculation of Harrault's (*15*) data gives the following results:

$$r_{HG}=.2988\pm.1228$$
$$r_{TG}=.5258\pm.0639$$
$$r_{HT}=.2821\pm.1241$$

In this case the net gain of a colony of bees was used, rather than the volume of nectar, and G therefore equals net gain. By substituting these values in Pearson's formula and solving we find that—

$$_{H}r_{TG}=.4826$$

The coefficient of correlation between net gain and temperature after correction is, therefore, somewhat lower than the direct correlation, but it is still positive.

In Table 2 the following coefficients of correlation are found:

$$r_{HG}=-.3806\pm.0935$$
$$r_{TG}=.7529\pm.0473$$
$$r_{TH}=-.1551\pm.1067$$

In this case, by reducing the effect of humidity to a constant, we have—

$$_{H}r_{TG}=.7594$$

No attempt has been made in the present investigation to ascertain the optimum temperature for the maximum change in weight of a colony of bees. Kenoyer (*20*) found under experimental conditions that the optimum temperature for nectar secretion for most of the Leguminosae which he tested was 15° C. (59° F.). He also called attention to the fact that the phenomenon of the accumulation of stored sugar from starch at low temperature in the twigs of woody plants is well known; and, further, presented data which show that the same is applicable to floral tissues. He likewise ascertained that, with an increase in temperature, the permeability of the protoplasts of the multicellular secreting hairs which cover the nectary of Abutilon rapidly increases. The osmotic pressures (intimately related to permeability in plants) of aqueous sucrose solutions were likewise found by Morse, as cited by Stiles (*32*), to vary directly with temperature, at temperatures generally encountered in working with plants. With the effect of low temperatures upon the accumulation of sugar on the one hand, and the effect of high temperatures upon permeability on the other, Kenoyer states that the evidence points to the conclusion that the secretion of nectar results from a balance between the two, and that the optimum temperature for secretion may be represented by the point where the negative graph representing temperature and sugar accumulation crosses the positive graph of permeability of protoplasts to sugar and temperature.

Phillips and Demuth (*31*), in referring to white clover (*Trifolium repens*), state that this species of Leguminosae may rarely be counted upon as a major honey source where the average summer temperature exceeds 75° F. (23.9° C.), and a more important consideration is that secretion is most rapid where there is a considerable daily range of temperature, the best results being observed when the night temperature is below 65° F. (18.3° C.), and the day temperature above that. The slight difference between Kenoyer's optimum temperature and the observations of Phillips and Demuth may be explained by the fact that the former was studying nectar secretion while the latter were referring to conditions as measured by the honey crop.

There are numerous records where low temperatures appear to have an important bearing upon nectar secretion. On the other hand, the literature of beekeeping contains many references, mainly observations by beekeepers, to the effect that high temperatures are necessary for an abundant secretion of nectar. Undoubtedly the physiological behavior of plants in nectar secretion varies somewhat with different species and under varying climatic conditions. Like Ono (*26*), Wilson (*33*) found that temperature makes but little difference in nectar production. In the case of branches of *Prunus laurocerasus*, however, he discovered that a temperature of at least 12° C. (53.6° F.) is necessary for the metamorphosis of the cell walls and the raising of the cuticle, and that after this activity of the nectary had passed a much lower temperature sufficed for continued secretion. Haupt (*17*) found that a certain minimum temperature was necessary to induce secretion and Demuth (*9*), in making observations to determine the temperature at which basswood (*Tilia americana*) begins to yield nectar, found that in northern Indiana this plant did not yield nectar until a temperature of 64° F. (17.8° C.) was reached.

From what has preceded, it is quite evident that considerable confusion exists regarding the true relation of temperature either to nectar secretion or to changes in colony weight. Much of this confusion is undoubtedly due to a lack of sufficient discrimination between the uses of the terms "nectar secretion" and "change in colony weight." So far as the changes in weight are concerned, the majority of the data indicate that during a honey flow the relation of these changes to temperature is positive. If there does exist a negative correlation between nectar secretion and temperature, it appears evident that either the honey flora in the vicinity of Somerset, Md., does not respond during the spring period as did the plants studied by Bonnier and Kenoyer, or else that the temperature has such a pronounced effect upon the behavior of the bees that the effect upon nectar secretion is largely obscured. Hot, dry weather often occurs at periods when no nectar is being brought to the hive; at the hottest times, however, it is not at all uncommon for bees to gather large quantities of honeydew of insect origin. Since the bee is a cold-blooded animal it is but natural to expect increased activity with increasing external temperature.

Table 3 lists the coefficients of correlation between net gain and the various weather factors of the previous day. It will be seen that the coefficient of correlation between the net gain and the average temperature for the entire spring period is .1783 ± .1059. This influence is positive but not otherwise especially significant, since the probable error is high. The correlation of net gain with average nocturnal temperature just preceding the gain is slightly higher, being .2151 ± .1043. Evidently, according to the data presented, temperatures of the day on which gains are made have a more direct influence on colony gains than do those of the previous day or night.

Table 3.—*Coefficients of correlation between net gain in colony weight and various weather factors of the preceding day, with their mean and standard deviations for the spring period*

	Diurnal average temperature	Diurnal variation in temperature	Diurnal average relative humidity	Diurnal variation in relative humidity	Hours sunshine	Solar radiation	Nocturnal average temperature	Nocturnal variation in temperature	Nocturnal average relative humidity	Nocturnal variation in relative humidity
Net gain	0.1783 ±.1059	0.3317 ±.0973	0.0329 ±.1093	0.0289 ±.1093	0.0246 ±.1093	−0.0804 ±.1087	0.2151 ±.1043	0.2472 ±.1027	0.0005 ±.1094	0.0721 ±.1088
Mean deviation	4.5261	4.9735	3.1578	4.6577	5.8682	6.4998	5.3682	4.6577	5.6840	4.1314
Standard deviation	2.4895	2.3113	2.3230	2.4526	2.7067	2.4146	2.8603	1.8416	2.0148	2.3304

The data taken during the fall period give a correlation coefficient of −.2310 ± .1185 between the average diurnal temperature and the change in weight. This figure is radically different from the correlation of .7529 existing between the average diurnal temperature and the net gain for the spring period. The probable error of the fall correlation is large, and this figure is therefore important chiefly because there is a negative correlation. This difference may be due in part to the fact that during the fall the activity of the colony in brood production is carried on under somewhat adverse conditions; that is, the effort necessary properly to care for the brood during the fall is proportionally greater than it is during the spring, and for this reason the bees will go to the fields under conditions otherwise not ideal. In such a case it may be that temperature has a more pronounced effect upon nectar secretion than upon bee behavior, and thus results in a negative correlation between average diurnal temperature and changes in colony weight. There seems little doubt but that a much greater effort is necessary on the part of the bees during the fall properly to carry on normal colony activity than is needed during the spring. Figure 1 illustrates a day in each of these two periods when the net gains are approximately identical. For the spring day, the morning loss was small and ceased at 8 o'clock. From this time on the colony gained slowly but steadily until the close of day. Apparently only partial loads were carried during most of the day, and the bees made short trips to the field. Had either one of these two suppositions not been true, the morning loss would have been larger, or, if the bees had carried maximum loads and had made short trips, only a small portion of the field force would have been engaged in gathering. The fall day shows a tremendous morning loss with a regaining of the original weight late in the afternoon. Such a heavy loss, scattered over so many hours, would justify one in believing that the entire field force was active, and that the individual bees made long trips and perhaps carried but partial loads. Figure 9 (*B*) illustrates another day (September 25) of the fall period when the bees must have made tremendous efforts to secure what nectar was available. Table 4 presents various data relating to the fall honey flow of 1922.

TABLE 4.—*Changes in weight of colony B, and various weather data during the fall honey flow*

Date (1922)	Diurnal change in weight	Nocturnal loss	Diurnal average temperature	Diurnal temperature variation	Diurnal average relative humidity	Diurnal relative humidity variation	Sunshine	Solar radiation	Nocturnal average temperature	Nocturnal temperature variation	Nocturnal average relative humidity	Nocturnal relative humidity variation	Morning loss
	Grams	*Grams*	°*F.*	°*F.*			*Hours*		°*F.*	°*F.*			*Grams*
Sept. 4	−130	80	87.5	20	69.3	44	11.7	438.3	77.5	9	97.1	5	450
5	−70	60	85.3	18	68.6	53	9.6	432.6	73.2	12	97.7	8	420
6	−50	60	87.0	26	62.2	60	12.8	490.6	74.9	13	95.3	11	460
7	−10	50	87.6	24	64.5	56	8.7	450.1	78.0	12	96.0	9	390
9	−110	90	81.4	13	79.8	39	5.2	277.5	74.7	7	98.8	4	690
10	200	130	83.9	15	68.6	47	8.1	410.9	75.7	6	97.7	10	410
12	−20	20	75.1	9	71.6	54	6.3	301.4	61.0	14	97.5	10	820
13	290	120	74.6	27	54.5	64	12.5	495.2	64.9	9	96.1	9	800
14	550	200	81.9	27	58.0	48	12.5	478.9	74.0	11	95.5	14	850
15	550	170	84.7	21	66.3	55	11.1	464.4	74.8	9	97.5	6	920
17	50	90	69.6	19	56.0	55	7.9	308.0	55.7	11	95.6	8	1,010
18	90	170	69.0	22	53.3	36	10.4	413.6	61.9	5	90.8	9	1,080
19	370	190	70.5	18	63.3	51	5.7	271.9	61.1	13	97.7	13	1,170
20	380	190	66.9	18	76.1	45	6.4	289.1	62.5	8	98.1	8	1,185
21	690	290	70.7	15	68.6	48	3.7	311.9	61.5	13	97.0	11	1,310
22	410	235	69.6	22	68.5	57	3.2	323.2	60.5	14	98.3	6	1,510
23	1,395	390	77.4	33	58.2	72	10.4	397.3	65.8	17	96.9	10	1,430
24	960	510	78.3	32	66.5	62	6.0	329.8	68.4	23	71.5	49	1,620
25	−220	170	67.7	18	46.2	71	12.0	540.0	50.1	13	91.1	19	1,690
26	310	220	61.2	25	49.2	70	12.0	474.5	51.2	10	96.7	20	1,360
27	1,110	340	68.9	32	60.0	60	12.0	448.9	61.6	13	96.5	17	1,260
28	680	300	71.3	34	58.8	70	11.7	404.3	61.2	10	97.0	15	1,495
29	300	230	72.9	22	71.9	51	7.9	346.5	62.0	17	97.8	7	1,300
30	660	300	73.0	28	64.5	56	11.8	413.5	60.2	16	96.9	11	1,190
Oct. 1	440	230	74.4	30	61.0	64	11.8	431.5	58.8	6	97.1	11	1,190
2	380	220	75.2	34	63.4	66	11.6	396.8	60.1	16	98.5	7	1,150
3	350	215	76.6	34	62.0	64	11.7	361.1	65.5	13	97.7	8	1,070
4	215	210	78.0	27	63.9	60	10.8	306.6	69.5	12	95.5	9	1,005
5	240	225	83.0	32	53.5	74	11.6	365.5	69.6	14	87.0	23	900

It must be recalled that the data in the spring and fall periods are not entirely comparable, since days were not chosen in the fall with a minimum net gain of 980 grams. The difference between the correlations of temperature and net gain in the two periods is, however, so striking as to call for an explanation, and no definite explanation seems to be available. In determining the cause of this difference in correlation in the two periods it must be remembered that there are striking differences in the conditions of the colony; in the spring the brood rearing is increasing and the population of the colony is not only greater but is made up predominantly of young bees; in the fall the population is smaller, brood rearing is decreasing, and many of the field bees are older than in spring. In the spring in the vicinity of the Bee Culture Laboratory the honey flow is heavy and nectar is abundant, whereas in the fall the daily gain is usually small and the plants yielding nectar do so in relatively small quantities. There may be an undetermined difference in the time of day at which nectar is secreted (as is found between clover and buckwheat, for example). In the spring, when nectar is unusually abundant, the gains may be largely attributable to the influence of increased temperature on bee activity, whereas in the fall the greater gains at lower temperatures may be associated with the inverse relationship which has been assumed between nectar secretion and temperature. Until more observations are made this must remain a matter of speculation.

It will be noticed in Table 2 that the correlation between diurnal variation of temperature and net gain in spring is .5967 ± .0704. A wide daily variation in temperature on days of good gathering has long been noted by beekeepers. There is some evidence, as previously pointed out, that a preceding low temperature is necessary to induce nectar secretion, and that once started this secretion will continue at higher temperatures. The correlation of this same variable with the fall changes of weight (Table 5) gives approximately the same figure, namely, .5570 ± .0863. The fact that diurnal variation of temperature affects the weight changes alike, both in the spring and fall, and the observation of this phenomenon by beekeepers, would indicate that this factor has a greater influence on nectar secretion than it does upon bee behavior.

For the fall period there is a correlation of −.7586 ± .0531 between the average diurnal temperature and morning loss. The morning loss is largely brought about by flight activity, and is therefore really a quantitative measurement of it. Since there exists for this period a positive correlation between morning loss and change of colony weight, this fact would seem to indicate that the colder the weather the greater the gain, as in reality the correlation between the changes of colony weight and diurnal average temperature (−.2310) actually shows, though to a small degree. The correlation between diurnal variation of temperature and change of colony weight is positive, and the correlation between morning loss and diurnal variation of temperature is also positive, despite the fact that there is a large negative correlation between morning loss and the diurnal average temperature. In calculating this latter coefficient of correlation, the average temperature for the entire diurnal period was used, while the period of morning loss covers but half of this time. Since the maximum average temperature comes later than the end of the period of average morning loss, as shown in Figure 10, a correlation with the temperature for the hours actually coinciding with morning loss would undoubtedly result in a lower correlation between these two variables. The evidence in favor of the theory that during the fall temperature has a greater effect on nectar secretion than it has on bee behavior is thus not materially weakened.

TEMPERATURE AND MIDDAY DECLINE

As previously pointed out, the cause for the midday decline has been attributed to high temperature and low relative humidity, both prevailing at that time of the day. The minimum of the average midday decline occurs from 1 to 2 p. m. (figs. 7, 8, and 10). The maximum of the average temperature comes from 3 to 4 p. m. (figs. 8 and 10), although it occurred an hour earlier during the 1922 spring honey flow (fig. 7). Although the midday decline occurs during the hot part of the day, it does not coincide with the period of maximum temperature. Moreover, the coefficient of correlation between net gain and average temperature is high and positive for the spring period, so that it is difficult to give a satisfactory explanation of the occurrence of the midday decline on the basis of high temperature and low relative humidity. During the fall the relation between change of colony weight and the average diurnal temperature is negative and the coefficient is small. From the standpoint of the net gain, the midday decline during the fall is large, but from the standpoint of weight changes it is small and barely noticeable.

TEMPERATURE AND NOCTURNAL LOSS

The relation of temperature to nocturnal loss is surprising in view of the widespread importance usually attributed to it by beekeepers. One naturally expects to find a higher rate of evaporation on warm nights following days of good gain than on cool nights. This relation, however, is small, the coefficient of correlation between net gain and nocturnal average temperature being but $.1754 \pm .1060$.

Temperature variation seems to have a more important bearing, the coefficient of correlation between net gain and nocturnal variation of temperature being $-.3439 \pm .0964$. One interpretation for this would be that when there is a great variation in temperature during the night the bees are forced constantly to modify their temperature-regulating organization in such a manner that the temperature of the brood-chamber may be maintained constant. In doing this the task of evaporation is interrupted, resulting in a negative correlation. In other words, from the standpoint of evaporation, an even temperature is more desirable than a high temperature, within, of course, reasonable limits.

During the fall period the relation between temperature and nocturnal loss is the opposite of that existing in the spring period, the coefficient of correlation between the average nocturnal temperature and nocturnal loss being $-.3391 \pm .1108$. It would be contrary to physical laws to expect a higher rate of evaporation during cold nights than during warm nights. An explanation of this negative correlation seems to lie in the fact that the relation between changes of weight during the day and the respective nocturnal losses is high. This in turn would indicate that the incoming nectar was promptly cared for, and the existing outside temperature, instead of primarily affecting the rate of evaporation, has its effect principally upon the general activity of the colony, resulting in the consumption of larger quantities of stores on cold nights.

The coefficient of .5136 ± .0922 between nocturnal loss during the fall and nocturnal variation of temperature can be explained in the same way. During the fall the amount of evaporation necessary is comparatively small because of the small amount of nectar gathered during this investigation, so that the various weather factors have little effect upon it, but have a considerable effect upon the work of the colony as a whole. The greater the range in temperature, the greater the consumption of stores, owing again, perhaps, to modification in the temperature-regulating arrangements of the colony. It is seen that variation of temperature has a greater influence upon the nocturnal loss, during both the spring and fall, than does the average nocturnal temperature. Variation of temperature at night produces noticeable disturbance.

RELATIVE HUMIDITY AND CHANGES IN COLONY WEIGHT

Even less is known regarding the influence of relative humidity upon changes in the weight of the colony than regarding the influence of temperature, probably largely because instruments for indicating relative humidity are not as widely distributed as are thermometers. Plant physiologists have, of course, studied the influence of relative humidity upon various phases of plant life, and to a limited extent upon nectar secretion. As in the case of temperature, there is no general agreement as to its relative value.

One of the difficulties encountered in determining the value of the influence of relative humidity upon any phase of plant or animal life is that relative humidity and temperature are intimately related. It is necessary, in a careful analysis of the influence of various weather factors upon physiological changes, to make due allowance for the influence of these variables upon each other. Wright (*34*), for instance, in recalculating the figures of Briggs and Shantz (*4*, *5*) found that temperature and not wet-bulb depression was the more important variable influencing the daily transpiration of plants. Patterson (*28*) states that relative humidity as a factor influencing the growth of higher plants has been greatly overestimated. He found that elongation in etiolated shoots of the common bean, growing in pure silica sand, either 20 per cent or 60 per cent saturated with water, proceeded as rapidly in a relative humidity of 30 per cent as in a relative humidity of either 60 per cent or 90 per cent. When growing in silica sand, 5 per cent saturated, they grew less rapidly in a relative humidity of 30 per cent than in a relative humidity of 60 per cent or 90 per cent, but grew as rapidly in a relative humidity of 60 per cent as they did in one of 90 per cent.

All figures pertaining to relative humidity in the present bulletin were obtained from a self-recording hygrometer maintained in the laboratory apiary. This instrument tended regularly to record too high percentages of relative humidity, and consequently the figures in some of the tables appear to be above the average. This error in the instrument should not greatly affect the coefficients of correlation in which relative humidity figured as one of the variables, since the error appears to be fairly constant. No attempt has been made to determine the optimum or minimum relative humidity necessary for any activity of the apiary.

RELATIVE HUMIDITY AND NET GAIN

It has been shown that temperature influences nectar secretion and changes in the colony weight. Similarly, plants doubtless respond to changes in relative humidity according to the species and the location in which they grow. Some species of plants are known to secrete nectar under conditions of the greatest possible humidity; on the other hand, arid and semiarid countries contain many nectar-producing plants.

Hommell (*18, p. 194*) states that, other conditions being equal, the quantity of nectar increases with an increase in the relative humidity of the air. Ono (*26*), in discussing the influence of moisture on nectar secretion in extrafloral nectaries, says that "moisture is one of the conditions most favorable to the secretion of nectar, and its influence seems to be more or less direct. Dry atmosphere is in all cases unfavorable to the secretion." He cites a case in which cut twigs of *Prunus laurocerasus* were placed in a water bottle and held under a bell jar of moist air for three weeks. Despite the fact that these nectaries were washed daily (an operation which will often terminate secretion), they continued throughout the experiment to secrete nectar without decreasing either its quantity or the quantity of sugar contained in it. Wilson (*33*), working with the same species of plant, found that after a branch of *Prunus laurocerasus* had been made to secrete nectar by being placed under a moist bell jar, it continued to do so without water and in the dry air of an ordinary room, until the whole branch had lost more than one-fourth of its weight by withering. Kenoyer (*20*) discovered that by increasing the relative humidity the production of water was increased, but not that of sugar from nectaries.

Bonnier (*1*) found that the secretion of nectar varies directly with relative humidity. Although he realized (*2*) the complex rôle which relative humidity plays in plant physiology, he made no corrections for the effect of other variables upon relative humidity in his studies on nectar secretion. In calling attention to the midday decline, and accounting for it by the low relative humidity and the high temperature prevailing at that time, he made no effort to assign more importance to one than to the other. The writer, in calculating Bonnier's data, found the coefficients of correlation, as stated under the discussion of temperature. In order to arrive at a corrected value for the effect of relative humidity by reducing temperature to a constant, we substitute in the following formula the numerical values of the proper coefficients (see p. 27 for correlation values), and obtain—

$$_Tr_{NH} = \frac{r_{NH} - (r_{NT}.\ r_{TH})}{\sqrt{(1 - r^2_{NT})(1 - r^2_{TH})}} = .6605$$

Thus the effect of temperature reduces the coefficient of .8040 between relative humidity and nectar secretion to .6605.

The substitution in the above formula of the coefficients calculated from Harrault's (*15*) data gives—

$$_Tr_{GH} = .1844, \text{ where } r_{GH} \text{ is } .2988$$

The writer found a correlation coefficient of $-.3806 \pm .0935$ between change in the colony weight and diurnal relative humidity for the spring period. In making a temperature correlation by means of the same formula, he found $_{T}r_{GH} = -.4058$. In this particular instance, it appears that dry atmosphere has a beneficial effect upon the change in colony weight.

The fall period showed less, or practically no, correlation between changes of colony weight and diurnal average relative humidity, the correlation being $-.0960 \pm .1240$.

It is interesting to note from Tables 2 and 5 that a wide variation of diurnal relative humidity has a beneficial effect upon change of colony weight, and that the coefficients of correlation in this case are higher than those with the diurnal average relative humidity.

The condition of the diurnal or nocturnal relative humidity of the day preceding has practically no effect upon change of colony weight.

RELATIVE HUMIDITY AND MIDDAY DECLINE

Figures 7, 8, and 10 show that the average minimum relative humidity is reached previous to the average low point of the midday decline. This fact, together with the existence of a negative correlation between net gain and diurnal relative humidity, makes it difficult to assign low relative humidity as the cause for the midday decline.

RELATIVE HUMIDITY AND NOCTURNAL LOSS

During the spring period the nocturnal relative humidity plays a small part in the nocturnal loss. The coefficients for both the average and the variation in relative humidity are small and have large probable errors.

For the fall figures these factors are more important. The coefficient of $-.4821 \pm .0961$ for the average nocturnal relative humidity with nocturnal loss signifies that the drier it is at night the more the colony loses in weight. The greater the variation in relative humidity during a night, the greater the loss, as is shown by the coefficient of correlation of $.5391 \pm .0888$. Thus it is seen that variation in relative humidity plays a more important part than the average relative humidity upon nocturnal changes in colony weight.

SOLAR RADIATION AND SUNSHINE

It is a well known fact that both solar radiation and sunshine exert a profound influence upon animal and plant life; it is therefore not surprising to find that these two factors play an important rôle in changes of colony weight. A number of investigators have attempted to learn the effect of light upon nectar secretion, but, as in other experiments upon nectar secretion, various species of plants have been used with the result that authorities differ in their conclusions.

Ono (*26*) placed *Ligustrum lucidium, Viburnum japonicum, V. opulus, Prunus yedoensis*, and *P. laurocerasus* in a dark moist chamber and found that their young extrafloral nectaries produced no nectar at all, but that their fully developed nectaries secreted in the dark equally as well as in the sunlight. In the case of *P. laurocerasus* this plant continued to secrete nectar in ample quantities for three weeks while placed in a dark chamber, the nectaries being washed daily.

He concludes that the influence of light on the secretions of the nectaries is of an indirect nature, except in the case of Vicia and some species of Euphorbia, these exceptions being noted by Haupt (*17*). As a matter of fact, Ono concludes that all external factors are of slight value in comparison with the inner conditions of the nectaries. Secretion, he thinks, may occur by mere chance; and the factors which are favorable to the life and growth of the plant at the same time promote the secretion of nectar.

Haupt (*17*) found that for certain plants, e. g., Euphorbia and Vicia, the secretion of nectar is profoundly influenced by light, especially by the red and yellow rays of the sun's spectrum. The secretion of nectar occurs only in light, and in darkness or in blue light nectaries already containing sugar resorb this substance.

Gardiner (*12*), in commenting on the discoveries of Wilson (*33*) regarding nectar secretion, says, "I am led to think that this goes far to explain both his own and Darwin's (*6, p. 403*) observations, that the exudation of nectar takes place more rapidly in sunlight, for according to my own observations as regards waterglands and the like it does not seem probable that the power of secretion as such is accelerated by light." However, Wilson (*33*) does not lay much stress on the effect of light upon secretion, as Gardiner would have one believe, for in Wilson's conclusions he states that many plants secrete as well in the light as in darkness, while others require either direct sunlight or strong diffused light for secretion. Harrault (*14*) observed that some plants can yield certain quantities of nectar under weak solar rays but that most plants do not yield nectar even in slight shade. In discussing the influence of external factors on plant transpiration, Livingston, in his revision of Palladin's work (*27, p. 138*), says that light is undoubtedly the most important.

In the present investigation the total hours of sunshine seem to have a somewhat greater effect upon net gain during the spring period than does solar radiation. The coefficient of correlation of the former with net gain is .6124 ± .0683, while for the latter with net gain it is .5525 ± .0760. In the attainment of the flowering stage of plants, Garner and Allard (*13*) found that length of day is much more important than the total amount of solar radiation received by the plant. This discovery is interesting in view of the fact that the secretion of nectar accompanies the attainment of the flowering stage for practically all of the important nectar-producing plants.

These writers state that—

> Except under such extreme ranges as would be totally destructive or at least highly injurious to the general well-being of the plant, the result of differences in temperature, water supply, and light intensity, so far as concerns the sexual reproduction, appears to be, at most, merely an accelerating or retarding effect, as the case may be, while the seasonal length of day may induce definite expression, initiating the reproductive processes or inhibiting them, depending on whether this length of day happens to be favorable or unfavorable to the particular species.

Further investigation along these lines may result in throwing more light on the effect of weather factors on bee behavior, and on plant behavior in so far as the secretion of nectar is concerned. A correlation of length of day with nectar secretion of various plants may likewise help to clear up the many differences in plant behavior which beekeepers attribute to differences of locality.

For the fall period the coefficients of correlation for both solar radiation and hours of sunshine with changes of colony weight are practically zero, while negative correlations, having large probable errors, exist between these variables and morning loss.

THE EFFECT OF UNKNOWN FACTORS ON CHANGES IN COLONY WEIGHT

In this investigation, correlations have been made between changes in colony weight and 10 different factors in the accompanying weather conditions, some of these also being used in correlations with the conditions for the day or night previous to the change in weight. There are so many external and internal factors which may influence the physiological processes of nectar-secreting plants and the behavior of bees in gathering and ripening nectar that it is not probable that the factors for which data were obtained are the only ones which may influence the changes in colony weight. For the purpose of ascertaining to what degree the influences have been determined and to what degree unknown factors are involved, an attempt has been made mathematically to find the values of all unknown factors. Such a determination throws no light on the actual character of these unknown factors, on the degree of their influence individually, or whether some are positive and some negative, but merely gives the mass value of all factors so far undetermined.

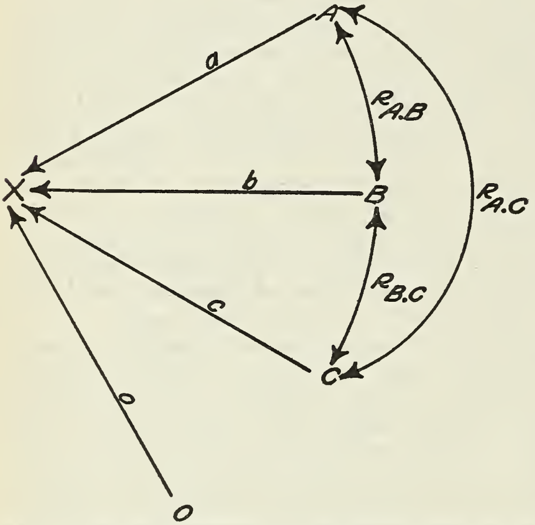

FIG. 11.—Graphical representation of quantities and their relations involved in the determination of coefficients of correlation

The method used in this work is based on Pearson's theory of multiple correlation. The square of the coefficient of multiple correlation between one variable and a number of others measures the extent to which the given variable is determined by the others, while 1 minus this square measures the degree of determination by independent residual factors. In a system of variables X, A, B and C, in which nothing is assumed of the causal relationships between them, X, which in this case is change in colony weight, is determined by the variables A, B, and C (weather factors) and by all other residual factors. This method has been described in detail by Wright (*35*).

In Figure 11, taken from Wright, the small letters represent the path coefficients, and the capital letters the variables, used in determining the coefficients of correlation. The path coefficients are not equal in value to the coefficients of correlation determined by direct correlation methods, but may be defined as the ratio of the standard deviation of X due to each variable to the total deviation of X. O represents all residual or unknown factors. From such data we have several simultaneous equations; as many in number as there are variables considered.

The following simultaneous equations are obtained:

$$\begin{aligned} r_{XA} &= a + br_{AB} + cr_{AC} \\ r_{XB} &= ar_{AB} + b + cr_{BC} \\ r_{XC} &= ar_{AC} + br_{BC} + c \end{aligned}$$

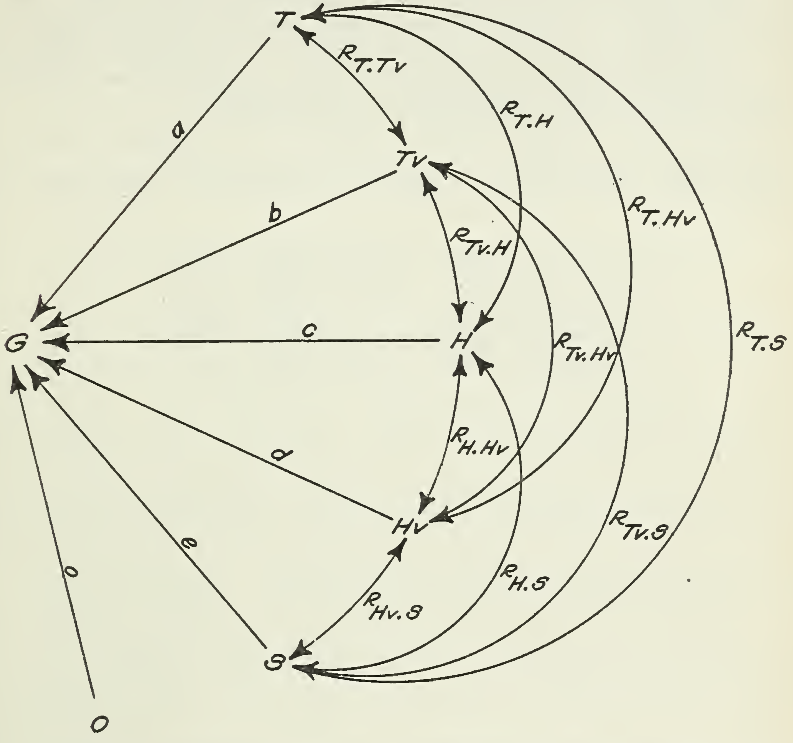

FIG. 12.—Graphical representation of quantities and their relations involved in the correlation of facto of increase of weight of the colony during the spring and fall honey flows

By solving these simultaneous equations the values of the path coefficients a, b, and c are derived. The total extent to which X is determined by the variables A, B, and C is obtained from the following formula (Wright):

$$1 - o^2 = ar_{AX} + br_{BX} + cr_{CX}$$

Applying this method to the correlations and other data obtained relating to changes in weight of the colonies during the spring honey flow (Table 2) and those for the fall honey flow (Table 5), calculations have been made by including five of the weather factors. In Figure 12 the symbols are as follows: G = net gain (changes of colony weight in the fall period), T = average temperature, Tv = temperature variation, H = average relative humidity, Hv = variation of relative humidity, S = hours of sunshine, L = nocturnal loss, and o = residual, unknown factors. It will be noted that only 5 of the weather factors are here included, although 10 were determined in the original data, but to have included all 10 would have made too unwieldy a calculation. In order to make comparison between the spring and fall periods the same variables were used in both cases. Hours of sunshine were used instead of solar radiation because this factor has a larger coefficient of correlation with net gain and because there is a high correlation between these two factors of themselves. None of the nocturnal factors were included in this calculation, as being of probably little value in their influence on net gain.

For these five weather factors is obtained the diagram shown in Figure 12.

From this diagram the following simultaneous equations are evolved:

$$
\begin{aligned}
r_{GT} &= a + br_{TTv} + cr_{HT} + dr_{HvT} + er_{ST} \\
r_{GT_v} &= ar_{TTv} + b + cr_{HTv} + dr_{HvTv} + er_{STv} \\
r_{GH} &= ar_{TH} + br_{TvH} + c + dr_{HvH} + er_{SH} \\
r_{GH_v} &= ar_{THv} + br_{TvHv} + cr_{HHv} + d + er_{SHv} \\
r_{GS} &= ar_{TS} + br_{TvS} + cr_{HS} + dr_{HvS} + e
\end{aligned}
$$

TABLE 5.—*Coefficients of correlation between changes of colony weight in the fall and various weather factors, with their mean and standard deviations*

	Change in weight	Nocturnal loss	Diurnal average temperature	Diurnal variation of temperature	Diurnal average relative humidity	Diurnal variation of relative humidity	Hours sunshine	Solar radiation	Morning loss	Nocturnal average temperature	Nocturnal variation of temperature	Nocturnal average relative humidity	Nocturnal variation of relative humidity
Change in weight		−0.8568 ±.0333	−0.2310 ±.1185	0.5570 ±.0863	−0.0960 ±.1240	0.3800 ±.1071	0.0595 ±.1248	−0.0341 ±.1251	0.5769 ±.0835	−0.1661 ±.1217	0.4455 ±.1003	−0.2022 ±.1201	0.3177 ±.1126
Nocturnal loss	.8568 ±.0333		−.3845 ±.1067	.5565 ±.0864	−.1867 ±.1208	.3886 ±.1063	.0039 ±.1252	−.1175 ±.1235	.7888 ±.0473	−.3391 ±.1108	.5136 ±.0922	−.4821 ±.0961	.5391 ±.0888
Diurnal average temperature	−.2310 ±.1185	−.3845 ±.1067		.0538 ±,1248	.2847 ±.1150	−.1184 ±.1234	.1813 ±.1211	.2362 ±.1182	−.7586 ±.0531	.9054 ±.0225	−.0203 ±.1251	−.0564 ±.1248	−.0730 ±.1245
Diurnal variation of temperature	.5570 ±.0863	.5565 ±.0864	.0538 ±.1248		−.4095 ±.1042	.6974 ±.0643	.5746 ±.0838	.2631 ±.1165	.2855 ±.1150	−.0280 ±.1251	.3363 ±.1110	−.2471 ±.1176	.3270 ±.1118
Diurnal average relative humidity	−.0960 ±.1240	−.1867 ±.1208	.2847 ±.1150	−.4095 ±.1042		−.5995 ±.0802	−.6268 ±.0760	−.5804 ±.0830	−.2792 ±.1154	.4255 ±.1025	.0073 ±.1252	.2618 ±.1166	−.3590 ±.1091
Diurnal variation of relative humidity	.3800 ±.1071	.3886 ±.1063	−.1184 ±.1234	.6974 ±.0643	−.5995 ±.0802		.4980 ±.0941	.3220 ±.1122	.3719 ±.1079	−.3536 ±.1095	.3785 ±.1073	−.1905 ±.1207	.3624 ±.1088
Hours of sunshine	.0595 ±.1248	.0039 ±.1252	.1813 ±.1211	.5746 ±.0838	−.6268 ±.0760	.4980 ±.0941		.7987 ±.0453	−.1218 ±.1233	.0204 ±.1251	−.1480 ±.1225	−.0014 ±.1252	.0437 ±.1250
Solar radiation	−.0341 ±.1251	−.1175 ±.1235	.2362 ±.1182	.2631 ±.1165	−.5804 ±.0830	.3220 ±.1122	.7987 ±.0453		−.1917 ±.1206	.1111 ±.1237	−.1674 ±.1217	−.0311 ±.1251	.0450 ±.1249
Morning loss	.5769 ±.0835	.7888 ±.0473	−.7586 ±.0531	.2855 ±.1150	−.2792 ±.1154	.3719 ±.1079	−.1218 ±.1233	−.1917 ±.1206		−.7425 ±.0561	.3823 ±.1069	−.2914 ±.1146	.3656 ±.1085
Nocturnal average temperature	−.1661 ±.1217	−.3391 ±.1108	.9054 ±.0225	−.0280 ±.1251	4255 ±.1025	−.3536 ±.1095	.0204 ±.1251	.1111 ±.1237	−.7425 ±.0561		−.1282 ±.1231	−.0113 ±.1252	−.1018 ±.1239
Nocturnal variation of temperature	.4455 ±.1003	.5136 ±.0922	−.0203 ±.1251	.3363 ±.1110	.0073 ±.1252	.3785 ±.1073	−.1480 ±.1225	−.1674 ±.1217	.3823 ±.1069	−.1282 ±.1231		−.4819 ±.0961	.5034 ±.0935
Nocturnal average relative humidity	−.2022 ±.1201	−.4821 ±.0961	−.0564 ±.1248	−.2471 ±.1176	.2618 ±.1166	−.1905 ±.1207	−.0014 ±.1252	−.0311 ±.1251	−.2914 ±.1146	−.0113 ±.1252	−.4819 ±.0961		−.9107 ±.0213
Nocturnal variation of relative humidity	.3177 ±.1126	.5391 ±.0888	−.0730 ±.1245	.3270 ±.1118	−.3590 ±.1091	.3624 ±.1088	.0437 ±.1250	.0450 ±.1249	.3656 ±.1085	−.1018 ±.1239	.5034 ±.0935	−.9107 ±.0213	
Mean deviation	2.9654	3.1723	5.2757	5.0343	4.4481	4.9309	6.0688	4.0000	4.5171	4.9654	3.2413	7.6205	1.4137
Standard deviation	2.2817	2.1021	2.5313	2.4705	2.1270	2.4627	2.8155	2.6521	2.7118	2.4564	1.9415	1.6700	1.7324

From values found in Table 2 are derived the following values of the correlations specified, used in calculating the value of the unknown factors influencing change of colony weight during the spring period:

DIURNAL

$r_{G \cdot T} = .7529$
$r_{G \cdot Tv} = .5967$
$r_{G \cdot H} = -.3806$
$r_{G \cdot Hv} = .4229$
$r_{G \cdot S} = .6124$

$r_{T \cdot Tv} = .5717$
$r_{T \cdot H} = -.1551$
$r_{T \cdot Hv} = .3899$
$r_{T \cdot S} = .5798$
$r_{Tv \cdot H} = -.7113$

$r_{Tv \cdot Hv} = .7855$
$r_{Tv \cdot S} = .7327$
$r_{H \cdot Hv} = -.7584$
$r_{H \cdot S} = -.6420$
$r_{Hv \cdot S} = .6780$

NOCTURNAL

$r_{L \cdot T} = .1754$
$r_{L \cdot Tv} = -.3439$
$r_{L \cdot H} = -.1264$
$r_{L \cdot Hv} = -.0654$

$r_{T \cdot Tv} = -.0739$
$r_{T \cdot H} = -.0043$
$r_{T \cdot Hv} = -.3373$

$r_{Tv \cdot H} = -.5655$
$r_{Tv \cdot Hv} = .4493$
$r_{H \cdot Hv} = -.6819$

Solving, we find the values of the path coefficients to be—

$$a = .6898,\ b = .0630,\ c = -.3217,\ d = -.2075,\ e = .1004$$

By knowing the values of the path coefficients, the value of o^2 can be determined from the following formula:

$$p_{GT}r_{GT} + p_{GTv}r_{GTv} + p_{GH}r_{GH} + p_{GHv}r_{GHv} + p_{GS}r_{GS} = 1 - o^2$$

and is found to be—

$$o^2 = .34705$$

the degree of determination of unknown factors for the spring period.

In determining the value of the unknown factors influencing nocturnal loss during the spring, only four variables were used, namely, nocturnal average temperature, temperature variation, nocturnal average relative humidity, and variation of relative humidity.

The values of the path coefficients were obtained by solving the following simultaneous equations:

$$\begin{aligned}
r_{LT} &= a + br_{TvT} + cr_{HT} + dr_{HvT} \\
r_{LTv} &= ar_{TTv} + b + cr_{HTv} + dr_{HvTv} \\
r_{LH} &= ar_{TH} + br_{TvH} + c + dr_{HvH} \\
r_{LHv} &= ar_{THv} + br_{TvHv} + cr_{HHv} + d
\end{aligned}$$

and are—

$$a = .07329 \qquad b = -.58681 \qquad c = -.57172 \qquad d = -.16688$$

The values of the unknown factors are determined by substituting the known values and solving the equation—

$$p_{LT}r_{LT} + p_{LTv}r_{LTv} + p_{LH}r_{LH} + p_{LHv}r_{LHv} = 1 - o^2$$

whence—

$$o^2 = .70268$$

It is quite evident in comparing the values of the unknown factors for the diurnal and nocturnal periods that so far as nocturnal loss is concerned the weather factors used have but little influence. The causes influencing the nocturnal loss during the spring period evidently lie chiefly within the colony itself.

The variables used in calculating the values of the unknown factors during the spring period were also employed in determining the values of the unknown factors for the fall period. The coefficients of correlation, derived from Table 5, and used for this purpose, are—

DIURNAL

$r_{G.T} = -.2310$
$r_{G.Tv} = .5570$
$r_{G.H} = -.0960$
$r_{G.Hv} = .3800$
$r_{G.S} = .0595$
$r_{T.Tv} = .0538$
$r_{T.H} = .2847$
$r_{T.Hv} = -.1184$
$r_{T.S} = .1813$
$r_{Tv.H} = -.4095$
$r_{Tv.Hv} = .6974$
$r_{Tv.S} = .5746$
$r_{H.Hv} = -.5995$
$r_{H.S} = -.6268$
$r_{Hv.S} = .4980$

NOCTURNAL

$r_{L.T} = -.3391$
$r_{L.Tv} = .5136$
$r_{L.H} = -.4821$
$r_{L.Hv} = .5391$
$r_{T.Tv} = -.1282$
$r_{T.H} = -.0113$
$r_{T.Hv} = -.1018$
$r_{Tv.H} = -.4819$
$r_{Tv.Hv} = .5034$
$r_{H.Hv} = -.9107$

Substituting the known values and solving the following simultaneous equations,

$$\begin{aligned}
r_{GT} &= a + br_{TvT} + cr_{HT} + dr_{HvT} + er_{ST}\\
r_{GTv} &= ar_{TTv} + b + cr_{HTv} + dr_{HvTv} + er_{STv}\\
r_{GH} &= ar_{TH} + br_{TvH} + c + dr_{HvH} + er_{SH}\\
r_{GHv} &= ar_{THv} + br_{TvHv} + cr_{HHv} + d + er_{SHv}\\
r_{GS} &= ar_{TS} + br_{TvS} + cr_{HS} + dr_{HvS} + e
\end{aligned}$$

we have—

$$a = -.26769,\ b = .74349,\ c = .16154,\ d = .04688,\ e = -.24127$$

Again, substituting these values for the path coefficients in the following formula,

$$p_{GT}r_{GT} + p_{GTv}r_{GTv} + p_{GH}r_{GH} + p_{GHv}r_{GHv} + p_{GS}r_{GS} = 1 - o^2$$

we find—

$$o^2 = .53609$$

Although the same diurnal variables were used in calculating the value of the unknown factors for the fall and spring periods, the values of the unknown factors for these periods are considerably different. There must be other important variables not included in the present data which emphatically influence the changes of colony weight during the fall.

The path coefficients for the nocturnal period during the fall were derived from the solution of the following four simultaneous equations:

$$\begin{aligned}
r_{LT} &= a + br_{TvT} + cr_{HT} + dr_{HvT}\\
r_{LTv} &= ar_{THv} + b + cr_{HTv} + dr_{HvTv}\\
r_{LH} &= ar_{TH} + br_{TvH} + c + dr_{HvH}\\
r_{LHv} &= ar_{THv} + br_{TvHv} + cr_{HHv} + d
\end{aligned}$$

In this case—

$$a = -.27206 \qquad c = -.07350$$
$$b = .29408 \qquad d = .29642$$

The solution of the equation—

$$p_{LT}r_{LT} + p_{LTV}r_{LTV} + p_{LH}r_{LH} + p_{LHV}r_{LHV} = 1 - o^2$$

therefore gives—

$$o^2 = .56148$$

It is interesting to note that the value of the unknown nocturnal factors during the fall is less than it is during the spring. With the same variables in use for calculating the value of o^2 during these two periods, the difference must be accounted for by variation in the behavior of the bees themselves.

The writer has calculated the value of o^2 from the coefficients of correlation which he determined from data by Harrault (*15*), given under the discussion of temperatures. In this case only two variables are available, namely, the average daily temperature and the relative humidity. The solution of the two simultaneous equations—

$$r_{GT} = a \quad + br_{TH}$$
$$r_{GH} = ar_{TH} + b$$

gives $a = .4779$ and $b = .1635$. By substituting these values in the formula—

$$p_{GT}r_{GT} + p_{GH}r_{GH} = 1 - o^2$$

we have—

$$o^2 = .6998$$

This figure shows the value of the unknown factors to be greater than that found in this work for the spring period.

A similar analysis of Bonnier's (*1*) data gives $o^2 = .3093$. This figure is lower than that given for the spring period. One must take into consideration that only temperature and relative humidity were considered by Bonnier and that activity of the bees does not enter into consideration in his work.

THEORETICALLY CHANGING WEATHER FACTORS AND PREDICTING RESULTING GAINS

One of the primary objects in presenting the following data is to demonstrate the value of accurately kept records of colony weight, together with weather records. By knowing how changes of colony weight vary with changes in the weather factors over a series of years, it would not be an impossibility to predict whether or not, in the long run, a certain locality would justify commercial beekeeping. Such data could also be used to plan migratory beekeeping and to learn perhaps whether a locality not suitable for honey production would be suitable for the production of bees or for queen rearing.

In order to give concrete examples in predicting gain under any variation of weather conditions, the necessary data may be taken from Table 6 and given, decoded, in Table 7. The following path coefficients are also used in the computations (see p. 42) for the spring period:

$$a = p_{GT} = .6898 \qquad d = p_{GHv} = -.2075$$
$$b = p_{GTv} = .0630 \qquad e = p_S = .1004$$
$$c = p_{GH} = -.3217$$

The formula for multiple regression, as given below, is used in arriving at the value of the predicted gain G':

$$G' = \overline{G} + a\sigma_G \frac{T' - \overline{T}}{\sigma_T} + b\sigma_G \frac{Tv' - \overline{Tv}}{\sigma_{Tv}} + c\sigma_G \frac{H' - \overline{H}}{\sigma_H} + d\sigma_G \frac{Hv' - \overline{Hv}}{\sigma_{Hv}} + e\sigma_G \frac{S' - \overline{S}}{\sigma_S}$$

This equation, in turn, is simplified to—

$$G' = \overline{G} + k_T(T' - \overline{T}) + k_{Tv} \,.\, (Tv' - \overline{Tv}) + k_H \,.\, (H' - \overline{H}) + k_{Hv} \,.\, (Hv' - \overline{Hv}) + k_S \,.\, (S' - \overline{S})$$

where—

$$k_T = 134.5550 \qquad k_{Hv} = -18.3968$$
$$k_{Tv} = 11.3678 \qquad k_S = 30.6658$$
$$k_H = -38.0266$$

Table 6.—*Mean and standard deviations of weather factors and changes of colony weight for the spring period*

	Net gain	Nocturnal loss	Diurnal average temperature	Diurnal variation of temperature	Diurnal average humidity	Diurnal variation of humidity	Hours of sunshine	Solar Radiation	Nocturnal average of temperature	Nocturnal variation of temperature	Nocturnal average humidity	Nocturnal variation of humidity
Mean	3. 9209	4. 2630	4. 6314	4. 9472	3. 5262	4. 6840	5. 5787	6. 1577	5. 4998	4. 7103	5. 8419	3. 8946
σ	2. 2289	2. 2908	2. 5385	2. 4705	2. 2448	2. 5140	3. 0406	2. 6808	2. 8169	1. 5717	2. 0333	2. 2687

Table 7.—*Decoded values of the means and standard deviations of variables used in determining G′*

Variable	Mean	σ
G	3023. 1600	1114. 4500
T	75. 8600	5. 7116
Tv	25. 7300	6. 1762
H	55. 0700	9. 4281
Hv	57. 0200	12. 5700
S	10. 5580	3. 6487

By substituting in either of the foregoing equations the various weather factors for each day, as given in Table 8, we obtain the effect, measured in grams, of the individual weather factors upon the gain of any particular day. Table 9 also gives these individual values for all days shown in Table 8.

Using this method, calculations have been made from the weather data shown in Table 8 to determine the predicted gain for each day of the spring period of the two years. The results of these calculations are presented in Table 10, which also gives the relation of the actual gain to the predicted gain in terms of percentage. It will be noticed that the average of the predicted gains is 100.53 per cent of the average of actual gains. This figure, however, has no biological significance, since all of the predicted gains were calculated on a daily basis.

The correlation between actual gain and predicted gain is theoretically obtained by the following formula:

$$r_{GG}' = \sqrt{ar_{GT} + br_{GTv} + cr_{GH} + dr_{GHv} + er_{GS}} = .8080$$

The actual and predicted gains may, therefore, be expected to agree within approximately 20 per cent of each other.

In order to determine how close this calculated correlation agrees with the true correlation between actual and predicted gains, the figures shown in Table 10 were correlated by the usual method for obtaining the coefficient of correlation.

In this case—

$$r = \left(\frac{\Sigma xy}{n} - \bar{x}\,\bar{y}\right)\frac{1}{\sigma_x \sigma_y} = .8844$$

These two values, actual, $r_{GG}' = .8844$, and predicted, $r_{GG}' = .8080$, are reasonably close and serve as an excellent check on all the computations involved.

TABLE 8.—*Morning loss, net gain, nocturnal loss, and intensity of weather factors during the spring period, colonies AB and 2, May, 1922 and May, 1923*

Date	Colony number	Morning loss	Net gain	Nocturnal loss	Diurnal average temperature	Diurnal variation of temperature	Hours of sunshine	Solar radiation	Diurnal average relative humidity	Diurnal variation of relative humidity	Nocturnal average temperature	Nocturnal variation of temperature	Nocturnal average relative humidity	Nocturnal variation of relative humidity
1922		*Gr'ms*	*Grams*	*Grams*	° *F.*	° *F.*					° *F.*	° *F.*		
May 10	AB	420	980	380	70.8	22	4.8	244.6	78.2	30	68.4	12	97.6	9
11	AB	240	5,900	700	83.3	31	14.2	637.3	45.4	63	71.3	18	74.0	17
12	AB	280	2,550	460	70.7	18	6.5	387.2	59.5	44	63.3	9	88.8	23
13	AB	210	2,410	520	74.6	23	9.1	538.6	53.8	33	66.9	14	94.9	22
14	AB	150	2,220	660	74.6	22	6.9	461.8	63.2	66	63.2	6	98.3	3
15	AB	320	1,110	510	73.5	23	10.9	579.6	65.9	55	58.9	13	94.3	23
16	AB	320	1,670	350	76.4	31	12.5	680.6	44.9	73	66.2	13	79.4	54
20	AB	150	3,700	420	76.2	28	9.8	655.0	54.7	52	66.9	12	96.3	13
21	AB	200	3,690	570	80.8	30	10.9	591.2	59.7	62	69.5	11	89.2	20
22	AB	200	4,610	600	80.7	23	11.4	627.6	62.7	48	68.2	13	96.3	18
23	AB	240	4,080	610	80.6	26	12.8	541.7	62.3	60	69.0	13	86.3	10
24	AB	270	3,320	690	80.7	27	14.4	588.2	56.2	47	65.4	19	65.6	44
1923														
May 18	2	370	3,530	630	72.7	29	8.7	510.7	49.2	62	63.9	12	92.7	21
19	2	550	3,080	780	76.3	27	14.4	594.1	50.8	70	62.2	11	87.0	32
20	2	390	3,100	960	75.5	23	8.4	445.6	62.5	50	69.0	3	94.5	8
21	2	520	3,240	1,080	76.7	14	8.1	502.6	69.7	46	63.6	10	87.4	13
22	2	590	2,540	890	68.4	17	12.6	660.9	56.7	42	56.3	11	88.2	26
23	2	460	1,140	480	64.7	17	3.7	301.3	50.7	59	52.5	12	92.4	17
24	2	150	3,520	740	69.6	32	14.6	653.6	41.2	73	53.6	15	84.0	37
25	2	110	3,960	980	74.6	37	13.7	661.5	38.0	79	58.6	13	73.9	43
26	2	130	4,350	840	80.3	35	14.3	672.5	44.0	63	67.1	14	85.6	33
27	2	70	4,370	820	84.9	34	13.2	597.5	47.8	69	69.3	15	80.6	20
28	2	170	3,630	810	78.6	28	9.2	484.1	65.9	47	70.6	10	91.3	11
29	2	80	3,940	800	86.3	32	14.2	562.9	50.1	69	71.6	12	83.8	25
30	2	510	1,670	580	71.4	12	3.4	263.4	66.5	38	59.6	13	93.3	15

TABLE 9.—*Differences between actual temperature, temperature variation, relative humidity, variation of relative humidity, hours of sunshine and their means, and the effect in grams that these deviations from their means have upon the net gains in colony weight of the spring period. The last column gives predicted gain, which is the sum of the effects of individual weather factors upon net gains plus* $\overline{G}$

Date	$T'-\overline{T}$	$(T'-\overline{T})\cdot k_T$	$Tv'-\overline{Tv}$	$(Tv'-\overline{Tv})\cdot k_{Tv}$	$H'-\overline{H}$	$(H'-\overline{H})\cdot k_H$	$Hv'-\overline{Hv}$	$(Hv'-\overline{Hv})\cdot k_{Hv}$	$S'-\overline{S}$	$(S'-\overline{S})\cdot k_S$	$\Sigma(m_1'-\overline{m}_1)\cdot k_1+\overline{G}$
1922											
May 10	−5.06	−680.8483	−3.73	−42.4018	23.13	−879.5552	−27.02	497.0815	−5.758	−176.5736	1,740.8626
11	7.44	1,001.0892	5.27	59.9083	−9.67	367.7172	5.98	−110.0128	3.642	111.6848	4,453.5467
12	−5.16	−694.3038	−7.73	−87.8730	4.43	−168.4578	−13.02	239.5263	−4.058	−124.4418	2,187.6099
13	−1.26	−169.5393	−2.73	−31.0340	−1.27	48.2937	−24.02	441.8911	−1.458	−44.7107	3,268.0608
14	−1.26	−169.5393	−3.73	−42.4018	8.13	−309.1562	8.98	−165.2032	−3.658	−112.1754	2,224.6841
15	−2.36	−317.5498	−2.73	−31.0340	10.83	−411.8280	−2.02	37.1615	.342	10.4877	2,310.3974
16	.54	72.6597	5.27	59.9083	−10.17	386.7305	15.98	−293.9808	1.942	59.5529	3,308.0306
20	.34	45.7487	2.27	25.8049	−.37	14.0698	−5.02	92.3519	−.758	−23.2446	3,177.8907
21	4.94	664.7017	4.27	48.5405	4.63	−176.0631	4.98	−91.6160	.342	10.4877	3,479.2108
22	4.84	651.2462	−2.73	−31.0340	7.63	−290.1429	−9.02	165.9391	.842	25.8206	3,544.9890
23	4.74	637.7907	.27	3.0693	7.23	−274.9323	2.98	−54.8224	2.242	68.7527	3,403.0180
24	4.84	651.2462	1.27	14.4371	1.13	−42.9700	−10.02	184.3359	3.842	117.8180	3,918.0272
1923											
May 18	−3.16	−425.1938	3.27	37.1727	−5.87	223.2161	4.98	−91.9160	−1.858	−56.9770	2,709.4620
19	.44	59.2042	1.27	14.4371	−4.27	162.3735	12.98	−238.7904	3.842	117.8180	3,138.2024
20	−.36	−48.4398	−2.73	−31.0340	7.43	−282.5376	−7.02	129.1455	−2.158	−66.1767	2,724.1174
21	.84	113.0262	−11.73	−133.3442	14.63	−556.3291	−11.02	202.7327	−2.458	−75.3765	2,573.8691
22	−7.46	−1,003.7803	−8.73	−99.2408	1.63	−61.9833	−15.02	276.3199	2.042	62.6195	2,197.0950
23	−11.16	−1,501.6338	−8.73	−99.2408	−4.37	166.1762	1.98	−36.4256	−6.858	−210.3060	1,341.7300
24	−6.26	−842.3143	6.27	71.2761	−13.87	527.4289	15.98	−293.9808	4.042	123.9511	2,609.5210
25	−1.26	−169.5393	11.27	128.1151	−17.07	649.1140	21.98	−404.3616	3.142	96.3519	3,322.8401
26	4.44	597.4242	9.27	105.3795	−11.07	420.9544	5.98	−110.0128	3.742	114.7514	4,151.6567
27	9.04	1,216.3772	8.27	94.0117	−7.27	276.4533	11.98	−220.3936	2.642	81.0190	4,470.6276
28	2.74	368.6807	2.27	25.8049	10.83	−411.8280	−10.02	184.3359	−1.358	−41.6441	3,148.5094
29	10.44	1,404.7542	6.27	71.2761	−4.97	188.9922	11.98	−220.3936	3.642	111.6848	4,579.4742
30	−4.46	−600.1153	−13.73	−156.0798	11.43	−434.6440	−19.02	349.9071	−7.158	−219.5057	1,962.7223

TABLE 10.—*Actual and predicted gains and percentage of actual gain to predicted gain in colony weight for the spring period*

Date	Actual gain	Predicted gain	$\frac{G'}{G} \times 100$	Date	Actual gain	Predicted gain	$\frac{G'}{G} \times 100$
1922				1923			
May 10	980	1,740	177.55	May 18	3,065	2,709	88.38
11	5,900	4,453	75.47	19	2,750	3,138	114.10
12	2,550	2,187	85.76	20	2,850	2,724	95.57
13	2,410	3,268	135.60	21	2,940	2,573	87.51
14	2,220	2,224	101.09	22	2,295	2,197	95.72
15	1,110	2,310	208.10	23	1,000	1,341	134.10
16	1,670	3,308	198.08	24	3,100	2,609	84.16
20	3,700	3,177	85.86	25	3,470	3,322	95.73
21	3,690	3,479	94.28	26	3,925	4,151	105.75
22	4,610	3,544	76.87	27	4,230	4,470	105.67
23	4,080	3,403	83.40	28	3,680	3,148	85.54
24	3,320	3,948	118.91	29	4,250	4,579	107.74
				30	1,765	1,962	111.16
				Total	75,560	75,964	100.53

To take specific days as examples, on May 14, 1922, the actual gain was 2,220 grams and the predicted gain for that day was 2,224 grams. By arbitrarily making relative humidity and the variation of relative humidity equal to the average of these factors, increasing the hours of sunshine from 6.9 to 14.2, and allowing the other weather factors to remain as they were, the predicted gain would be 2,928. Thus the changing of these three weather factors theoretically resulted in a gain of 704 grams.

On May 23, 1923, the net gain is low in comparison with the other days, being 1,000 grams. From the standpoint of the maximum changes of colony weight, the following ideal weather factors were substituted for those actually found on this date:

Hours of sunshine 14.6 hours, instead of 3.7.

Average diurnal temperature 86° F., instead of 64.7° F.

Average relative humidity 38 per cent, instead of 50.7 per cent.

The remaining weather factors were not changed. Under such conditions, the predicted gain is 5,025 grams. The actual predicted gain with existing weather factors on May 23 is 1,341 grams. By changing the weather factors, a predicted net gain of 3,684 grams results. The weather factors here substituted actually occurred within a few days of the 23d of May and so are not at all unreasonable. The combination of optimum conditions occuring all on the same day is, of course, entirely problematical; these examples are given, however, merely to show the importance of the various weather factors on changes of colony weight.

CONCLUSIONS

Although the weather is beyond the control of the beekeeper, a knowledge of the influence of weather factors upon honey crops in various parts of the country will be of great value in developing the best beekeeping regions of the United States.

To gain this knowledge it is first of all necessary to keep certain colonies under observation, recording at frequent and regular intervals the weight of each, and recording such accompanying phenomena of the weather as may reasonably be supposed to influence either the secretion of nectar or the activities of the bees.

A confirmation of the practical value of carefully kept records of this sort is shown by their use in computing predicted changes of colony weight.

A mathematical analysis is necessary to show the true relationship between these changes and the attendant weather factors, and without such mathematical analysis the relative importance of various weather factors upon the changes can not be shown.

Correlations have been made between the changes in the weight of two colonies of bees during the various periods of the day and several weather factors. From the standpoint of the results of these comparisons the most important weather factors of those included in this investigation affecting net gain during the spring period, and, in order, the values of their coefficients of correlation, are, average temperature, .7529; hours of sunshine, .6124; temperature variation, .5967; solar radiation, .5525; variation of relative humidity, .4229; and average relative humidity, –.3806.

Weather factors have but little influence upon nocturnal loss during the spring period, the coefficients of correlation being, temperature variation, –.3439; average temperature, .1754; average relative humidity, –.1264; and variation of relative humidity, –.0654.

During the fall period diurnal changes in colony weight were differently influenced by weather factors, the coefficients of correlation between these changes and the several weather factors being, for temperature variation .5570, variation of relative humidity .3800, average temperature –.2310, average relative humidity –.0960, hours of sunshine .0595, and solar radiation –.0341.

During the fall period the influence of the weather factors upon nocturnal loss was greater than in the spring, the coefficients of correlation being, for variation of relative humidity .5391, variation of temperature .5136, average relative humidity –.4821, and average temperature –.3391.

The importance of the unknown factors influencing net gain during the spring period was less than that of the unknown factors influencing diurnal changes in the colony weight during the fall, the value of the former being .3470, while that of the latter was .5360.

For the spring period the value of the unknown factors upon nocturnal loss was .7026, while that for the fall period was .5614.

Factors influencing the secretion of nectar probably do not similarly influence changes in colony weight.

The changes in the weight of two colonies of bees placed side by side continuously resembled each other.

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